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by

William Joseph Schworer III

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Nationwide Mobile Communication Systems

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Submitted in partial fulfillment of the
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ABSTRACT

This thesis provides a basic understanding of nationwide terrestrial and satellite mobile communications and tracking technologies. Covered are systems currently available and in development. An analysis of user costs is performed for comparison. A more detailed mobile satellite cost/benefit analysis for use by the trucking industry is also presented. Follow-on chapters contain discussions of the basic economic issues faced by satellite system operators and the regulatory history of mobile satellite services. Contained in the appendices are a more detailed discussion of mobile satellite systems and a layman's explanation of communication and navigation technologies. The conclusion presents comments on the possible future direction of these new mobile communication services and makes recommendations for trucking industry use.

TABLE OF CONTENTS

I. INTRODUCTION -- 1

A. SYNOPSIS -- 1

B. BACKGROUND -- 3

C. REGIONAL AND NATIONWIDE TWO-WAY COMMUNICATIONS AND TRACKING TECHNOLOGIES ------------- 7

D. USES FOR NATIONWIDE TRACKING AND COMMUNICATION SYSTEMS ------------------------------- 11

E. CONCLUSION ---------------------------------- 21

II. OVERVIEW OF MOBILE COMMUNICATIONS SYSTEMS ------- 23

A. INTRODUCTION -------------------------------- 23

B. RADIO DETERMINATION SATELLITE AND MOBILE SATELLITE SYSTEMS --------------------------- 23

C. U.S. GOVERNMENT TRACKING SYSTEM ------------- 42

D. METEOR BURST COMMUNICATIONS ----------------- 45

E. CELLULAR RADIOTELEPHONE --------------------- 56

F. SPECIALIZED MOBILE RADIO -------------------- 89

G. MOBILE DATA SYSTEMS ------------------------- 101

H. PAGING -------------------------------------- 114

I. SUMMARY COMPARISON OF MOBILE COMMUNICATION SERVICES AND TECHNOLOGIES ------------------- 123

J. CONCLUSIONS --------------------------------- 123

III. USER COST COMPARISON ---------------------------- 129

A. INTRODUCTION -------------------------------- 129

B. USER COST MODEL ----------------------------- 129

C. EQUIPMENT AND SERVICES ---------------------- 134

D. USER COST ANALYSIS ---------------------------- 143

E. CONCLUSION ---------------------------------- 175

IV. SATELLITE TRACKING AND COMMUNICATIONS QUALITATIVE COST BENEFIT ANALYSIS ---------------------- 178

A. PURPOSE AND SUMMARY ------------------------- 178

B. BACKGROUND ---------------------------------- 178

C. LIMITATIONS OF THE ANALYSIS ----------------- 179

D. METHODOLOGY --------------------------------- 180

E. METHODS USED TO EVALUATE INVESTMENT IN SATELLITE TECHNOLOGY ----------------------- 184

F. SOURCES OF DATA ----------------------------- 187

G. DATA MANIPULATION --------------------------- 188

H. QUALITATIVE MODEL OUTPUT -------------------- 198

I. EVALUATION OF MODEL OUTPUT ------------------ 199

J. COMPARISON OF MODEL OUTPUT WITH ACTUAL OPERATING STUDIES --------------------------- 228

K. CONCLUSIONS --------------------------------- 233

V. OVERVIEW OF SYSTEM ECONOMICS ------------------- 238

A. INTRODUCTION -------------------------------- 238

B. COMMUNICATION SYSTEM ECONOMICS -------------- 238

C. PROJECTED RDSS AND MSS MARKET SIZE AND REVENUES ------------------------------------ 255

D. SYSTEM COST MODEL --------------------------- 268

E. TRANSPONDER AVAILABILITY -------------------- 288

F. GEOLOCATION SYSTEM COST TRADEOFFS ----------- 291

G. CHALLENGES FACED BY RDSS AND MSS SYSTEMS ---- 296

H. SUMMARY ------------------------------------- 304

VI. REGULATORY HISTORY OF MOBILE SATELLITE SYSTEMS -- 308

A. INTRODUCTION -------------------------------- 308

B. REGULATORY AGENCIES ------------------------ 309

C. REGULATORY HISTORY OF MOBILE SATELLITE SYSTEMS BETWEEN 1971 AND 1979 -------------- 309

D. FEDERAL COMMUNICATION COMMISSION RULINGS ON RDSS -- 311

E. FCC RULINGS ON MSS ------------------------- 315

F. TREATMENT OF RDSS AND MSS AT THE WORLD ADMINISTRATIVE RADIO CONFERENCE FOR THE MOBILE SERVICES (WARC MOB-87) -------------- 324

G. APPLICATIONS TO USE FIXED SATELLITE SERVICE TRANSPONDERS FOR MOBILE SATELLITE USE ------- 331

H. PROPOSAL FOR A DIGITAL LAND MOBILE MESSAGING SERVICE -------------------------- 333

I. FCC PROPOSAL TO ALLOCATE ADDITIONAL L-BAND SPECTRUM FOR A GENERIC MOBILE SATELLITE SERVICE -------------------------------------- 336

J. INTERNATIONAL MARITIME SATELLITE ORGANIZATION (INMARSAT) ---------------------------- 338

K. PETITION BY ORBITAL SCIENCES CORPORATION TO ESTABLISH A MOBILE DATA SERVICE USING LOW-EARTH ORBIT SATELLITES --------------------- 340

L. OBSERVATIONS ON THE REGULATORY PROCESS ------ 345

M. CONCLUSION --------------------------------- 346

VII. CONCLUSIONS ------------------------------------ 348

A. REVIEW ------------------------------------- 348

B. FUTURE SYSTEMS ----------------------------- 355

C. TRUCKING INDUSTRY USE ---------------------- 357

D. POTENTIAL DEPARTMENT OF DEFENSE TRANSPORTATION SYSTEM APPLICATIONS ------------------- 359

E. EPILOGUE ----------------------------------- 362

APPENDIX A: EXISTING AND PROPOSED MOBILE SATELLITE SYSTEMS ---------------------------------- 364

A. INTRODUCTION ------------------------------- 364

B. INMARSAT-C ---------------------------------- 364

C. GEOSTAR -------------------------------------- 396

D. QUALCOMM OMNITRACS -------------------------- 428

E. AMERICAN MOBILE SATELLITE CORPORATION AND TELESAT MOBILE COMMUNICATION SYSTEM --------- 439

F. GEOSTAR MESSAGING CORPORATION DIGITAL LAND MOBILE SATELLITE SERVICE ------------------- 463

G. ORBITAL COMMUNICATIONS CORPORATION PROPOSAL FOR A LOW-ORBIT MOBILE SATELLITE SYSTEM ----- 467

APPENDIX B: COMMUNICATION, SATELLITE, AND NAVIGATION CONCEPTS ---------------------------------- 489

A. PURPOSE -------------------------------------- 489

B. FUNDAMENTALS --------------------------------- 489

C. SPECIALIZED MODULATION TECHNIQUES ----------- 524

D. ADVANTAGES OF DIGITAL COMMUNICATION --------- 548

E. SATELLITE COMMUNICATIONS -------------------- 552

F. SATELLITE RANGING ---------------------------- 577

G. POSITION DETERMINATION SYSTEMS -------------- 590

APPENDIX C: MOBILE COMMUNICATIONS COST/BENEFIT SPREADSHEET ------------------------------ 620

APPENDIX D: OPERATING STATISTICS AND COST ANALYSIS --- 655

LIST OF REFERENCES ------------------------------------ 664

INITIAL DISTRIBUTION LIST ----------------------------- 673

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I. INTRODUCTION

A. SYNOPSIS

Continuing advancements in electronic and computer technology have increased the capabilities of mobile voice and data communications systems. Satellite-based systems which use small, lightweight terminals and antennas have been fielded, and other mobile satellite systems are currently in development. Earth-based local area systems are also being networked to provide communications on a regional or nationwide basis.

Transportation, particularly the trucking industry, is forecast to have one of the largest initial requirements for these high technology communication and information systems. Trucking firms can operate their geographically dispersed fleets more efficiently and effectively by knowing the location of their assets and being able to communicate with drivers in a timely manner. This information is also of value to shippers which manage their logistics systems to minimize the amount of material in transit and held at destinations. When properly used, these communications systems can also provide carriers with strategic market and service differentiation. Many other applications exist as well, and are listed in Section C.2 of this chapter.

The investment and recurring costs of regional and nationwide mobile communication technology can be substantial, particularly if large quantities of equipment are used. There is also competition between satellite and networked terrestrial (earth-based) systems in terms of service capabilities, geographic coverage, and expenses. Potential users of advanced mobile communication technologies should understand the basic capabilities, strengths, limitations, and costs of each type of system. Additionally, users need to understand how to maximize the administrative, operational, and strategic benefits of these new technologies.

This thesis provides the reader with a basic knowledge of regional and nationwide mobile communications and tracking technologies. Covered are systems currently available and in development. The thesis places more emphasis on mobile satellite systems because of the widespread publicity, technology, costs, and trucking industry interest. Discussed in less detail are non-satellite systems which, when networked, may also serve regional and nationwide mobile communication and tracking needs.

An analysis of satellite and terrestrial system user costs is performed for comparison. A much more detailed cost/ benefit model of satellite systems is also presented. These analyses show that both satellite and conventional ground-based tracking and communications systems may make economic sense for segments of the trucking business. Follow-on

chapters contain discussions of the basic economics issues faced by satellite system operators and the regulatory history of mobile satellite services. Contained in the appendices are a laymen's explanation of communication and navigation technologies and a more detailed discussion of mobile satellite systems. Finally, the conclusion presents recommendations for trucking industry use and comments on the possible future direction of this new mobile communications, tracking, and information industry.

B. BACKGROUND

Advanced technology mobile two-way communications and tracking systems have been developed for the following reasons.

1. <u>Ability to Overcome the Limitations of Conventional Mobile Radio Communications</u>

The mobile radio industry, from its beginning in the 1920's through the mid-1970's, produced few significant technological innovations. There were also few changes in users' applications. This was due to frequency and coverage restrictions, system investment costs, and the limitations of technology. [Ref. 1:p. 1]

a. Frequency and Coverage Restrictions

The High Frequency (HF) band, extending in frequency from three megahertz (millions of cycles per second, abbreviated MHz) to 30 MHz, is capable of long-range mobile communications. However, varying propagation conditions (the

way in which radio waves travel from one point to another) make the continuous use of just one or a few frequencies unreliable. The HF band is extremely crowded, and no spectrum is allocated to support commercial long-distance land mobile communications.

Very High Frequency (VHF), from 30 to 300 MHz and Ultra High Frequency (UHF), from 300 to 3000 MHz, radio systems are constrained by the laws of physics to a coverage area generally within the transmitting antenna's line of sight. This range can be extended by a network of receivers and transmitters, known as repeaters, which rebroadcast the signal over larger but still limited areas. The typical VHF and UHF mobile radio system consists of a medium power transmitter (100 to 1000 watts) feeding an antenna located high above the surrounding terrain. The combination of transmitter power and antenna height maximizes the coverage area. Mobile radios are restricted to certain frequency ranges within the VHF and UHF bands. The FCC grants licenses and assigns specific frequencies to users of conventional two-way radios. Depending on a number of variables, users will be granted exclusive use of a frequency or will be required to share the frequency with other users. In most urban areas the limited spectrum allocated to conventional VHF and UHF mobile radio has reached saturation. This led to the demand for additional frequencies and more spectrum-efficient mobile radio systems.

b. System Investment Costs

As conventional earth-based two-way radio systems are extended geographically, the average number of subscribers per unit of area will diminish. In general, this is because the population density and number of system users declines as the distance from the center of an urban area increases. Unit costs for extending areas of ground-based radio coverage are by and large constant. Eventually, a point is reached where it is no longer economical to geographically expand the system. This prevents ground-based systems from providing complete nationwide two-way radio coverage. [Ref. 1:p. 9]

There are many sections of highway and entire areas of the country, particularly in the West, which have population densities below the amount necessary to support commercial ground-based systems. However, a need for service in these areas still exists, and in the aggregate this constitutes a sizeable demand [Ref. 2:pp. 31-37]. Mobile communication satellites are designed in part to overcome the coverage limitations of terrestrial radio.

c. Limitations of Radio Technology

In general, prior to the use of integrated circuitry, the components used in mobile two-way radios were relatively simple and required more physical space and electrical power. The engineering and construction of some of these components made operating at the higher UHF frequencies difficult. The use of crystal oscillators limited these

radios to just a few channels. Voice was virtually the only mode of communication. These factors combined to increase frequency congestion and reduce communication system efficiencies.

To meet these challenges, efficient and miniature components were designed to function at the higher UHF frequencies. Large-scale integrated circuits were incorporated to govern radio operation, control frequencies, and enable data transmission. Computer systems were designed to control the operation of large numbers of mobile radios. These innovations have increased the efficiency and effectiveness of mobile communications systems.

2. Deregulation of the Telecommunications Industry

Many innovations and new services have come about as a result of competition from reduced regulation in the telecommunications industry [Ref. 1:p. 1]. The ability to merge radio systems into regional and nationwide networks is one outgrowth.

3. Deregulation of the Trucking Industry

Deregulation of the trucking industry has eliminated many firms which were inefficient or unable to rapidly adapt to a changing market. Profit margins have fallen in many cases. New forms of competition, new rate structures, and new concepts of services have emerged. In this environment, a demand has logically appeared for new technologies which lower

costs, provide increased levels of customer service, and differentiate the firm from competitors.

C. REGIONAL AND NATIONWIDE TWO-WAY COMMUNICATIONS AND TRACKING TECHNOLOGIES

Three main groups of technologies enable regional and nationwide mobile two-way communications. Each of these groups uses a different blend of technology to convey information, and they may be interchangeable in many applications. Competition between technologies is based primarily on price, service levels, coverage capability, and stage of implementation.

1. Satellite

Satellite communication technology is very capital intensive but can be very economical when compared with the alternatives. Large earth-coverage areas eliminate the communication density problems and coverage limitations of terrestrial radio systems. Communication satellites have high message throughput capabilities because of their efficient use of communication modes and spectrum. These factors combine to enable large volumes of communication at affordable user costs.

Until recently, commercial satellite communications required expensive, bulky equipment and large antennas which could be operated only from fixed locations or ships. The technology has now evolved to the point where inexpensive,

low-power mobile terminals can be used for position reporting and voice and data communications.

The satellite technologies which enable regional and nationwide mobile communication and tracking are classified as the Radiodetermination Satellite Service (RDSS) and the Mobile Satellite Service (MSS). RDSS and MSS are intended to serve different user groups. By definition and system design, RDSS provides radiolocation and radionavigation information with a limited digital message capability. MSS is structured to provide rural radio and telephone services as well as aeronautical and land mobile communications. MSS is designed to have both a voice and data capability; RDSS is not. [Ref. 3]

2. <u>Meteor Burst</u>

Meteor burst communications systems reflect radio waves off the ionized trails left by meteors as they enter the atmosphere and disintegrate. Transmissions are limited to data only and have a range of up to 1200 miles. Nationwide mobile coverage requires a network of four or five ground-based master stations. Meteor burst is used in a number of fixed site applications, and has only recently been put into mobile use. Meteor burst is less capital intensive than other nationwide and regional systems because it does not require an expensive infrastructure. [Ref. 1:pp. 39-42]

3. Networked Terrestrial Systems

Earth-based systems can be networked to provide a regional and national communications capability. However, geographic coverage gaps will still exist because of the economic limitations associated with subscriber density in sparsely populated areas.

a. Cellular Radio Service

With this system, a geographical area is honeycombed with many cells, hence the name "cellular." Each cell has its own low-powered, low-height radio transmitter and receiver. Computer-controlled equipment connects the cellular radio with the public switched-telephone network and automatically transfers the call between sites when the mobile transmitter moves from one cell to the next. This permits the same frequencies to be reused without causing interference in other parts of a metropolitan area, and enables a much larger number of users to be served than with other conventional radiotelephone systems.

Cellular telephone was originally designed for voice, but advances in technology enable facsimile (FAX) and data transmissions.

Cellular radiotelephone systems operated in different geographic areas are becoming networked through roaming agreements. This enables a subscriber in one geographic area to use cellular systems in other areas without becoming a subscriber to those systems. "Follow me roaming"

services allow callers to contact a cellular subscriber who is outside the normal service area by dialing the home area cellular number. A computer automatically intercepts and reroutes the call over the telephone network to the appropriate cellular location. [Ref. 1:pp. 12-18]

b. Specialized Mobile Radio (SMR)

Like cellular, SMR was designed to relieve frequency congestion and increase system capacity. SMR is intended for the same uses as conventional two-way radio, but can provide mobile telephone, paging, and mobile data services as well. SMR systems have between five and 20 channels connected together (trunked) by an automated network controller. When a unit requests to transmit, the network controller selects the next free channel and assigns it for use. Trunking five to 20 channels increases the communication capacity of each channel by a factor of four to six, respectively. SMR systems are presently located in at least twice as many areas as cellular systems. SMR manufacturers have designed ways to network individual SMR systems, and many transportation corridors are covered. Work is underway to expand SMR networking on a regional and nationwide basis. [Ref. 1:pp. 26-31]

c. Mobile Data Systems

Mobile data systems are designed to optimize the transmission of data instead of voice. Public mobile data systems have been built in Los Angeles, Chicago, and New York.

These systems have also been networked with a previously private system to provide public regional and national coverage. Further expansion of public mobile data systems will probably be limited to the more densely populated areas. [Ref. 1:pp. 43-47]

d. Paging

Paging is a one-way only service and is available in almost all areas. The major limitation of paging is that the sender can never be sure the message was received. Paging systems range in complexity from simple "beepers" to alpha-numeric digital displays. Because paging systems are so efficient, many companies simultaneously broadcast a page over multiple transmitters. These "wide-area" services enable coverage of entire states. Several companies have recently set up nationwide paging networks. [Ref. 1:pp. 19-25]

D. USES FOR NATIONWIDE TRACKING AND COMMUNICATION SYSTEMS

1. The Trucking Industry

Trucking companies, like most businesses, want to accomplish at least three things: increase revenue, reduce costs, and improve customer service. In general, improving revenue requires more equipment, people, and service differentiation. Reducing costs necessitates higher operating efficiencies and equipment utilization, less employees and overhead. Increased customer service can require more trucks, terminals, and employees. By providing decision makers with

lower cost and more timely information, nationwide communications, tracking, and management information systems can help trucking firms balance these opposing objectives to a greater extent than previously possible.[1] Additionally, shippers and receivers have recognized that timely information is essential for their business logistics management.

For example, once a conventionally-equipped long-haul truck leaves the terminal or shipper's loading dock, it is no longer under positive management control. The dispatcher and customer service agents must wait for the driver to check in, usually by long-distance telephone, in order to know the truck's location. Cumulative time off the highway and telephone expenses erode slim profit margins. Lack of timely position information limits management's ability to operate the fleet as efficiently as possible, and restricts the amount and timeliness of information which can be provided to the customer.

Regional and nationwide communication and tracking systems can potentially improve this situation. The ability to constantly track and communicate with a trucking fleet can boost revenues by increasing the number of enroute pick-ups. The extra time available for driving enables more total freight to be hauled. Costs can be cut by increasing operating efficiencies, reducing personnel and overhead.

---

[1]Telephone conversation between Mr. Paul Pecka, Sony Corp., and the author, 26 April 1989.

Customer service can be improved through the ability to monitor and communicate with the truck in almost real time. This is of particular importance with Just-In-Time (JIT) applications, where inventories are held to minimum levels and delivery schedules are critical. Timely knowledge of service difficulties allows shippers and receivers to make alternate arrangements to avert stock-outs and shut downs. Figure 1 comparatively illustrates how U.S. industry in general has a much larger JIT transportation problem than does Japan, a world leader of JIT [Ref. 4]. For these reasons the trucking industry is forecast be one of the largest initial users of regional and nationwide tracking and communication systems.

2. Trucking Industry Applications

Some potential trucking industry uses for regional and nationwide tracking and communications are detailed below.[2]

a. Sales and Marketing Revenue Opportunities--The improved response to short-fused requests for service, ability to make time commitments, positive tracking and control of linehaul trucks, and the ability to differentiate service are all marketing assets. This product differentiation and positive control can be used as a sales tool to improve revenue. Types of sales and marketing revenue include:

(1) Value of market differentiation.

(2) Increased revenues from sensitive shipments:

i. Hazardous Materials.

ii. Explosives.

---

[2]Potential uses listed in the following sections were compiled from numerous documents, conversations, and brainstorming sessions with various individuals.

Distances Between Key Centers in Japan As Compared to the U.S.

SCALE IS APPROXIMATE

Figure 1. Distances Between Key Centers in Japan as Compared to the U.S.

iii. Ability to provide constant surveillance services without the additional expense of escort vehicles, two-way radios, and manpower.

iv. Remote monitoring of high/low temperatures, excessive road shocks, and unauthorized cargo access.

(3) Increased revenues from ability to guarantee time commitments.

(4) Increased "Just-In-Time" market penetration.

(5) Potential for direct data input into customer Electronic Data Interchange (EDI) systems.

b. Operating Expense Reductions

(1) Deadhead avoidance and out of route miles. Tracking and communication with drivers after initial dispatch allows reassignment to meet changing requirements. This can improve fleet positioning and driver utilization. Ability to follow a driver's course allows tracking and control of intentional out-of-route miles.

(2) Driver and Equipment Productivity.

i. Decrease in time required to get to a telephone and return to highway (decelerate, exit the highway, locate telephone, reenter highway and return to speed).

ii. Information provided over the telephone is often loosely structured and it is difficult to control the time and content of the call. Use of structured alphanumeric messaging can decrease total communication time. Manual transcription of information and non-business discussions are eliminated.

iii. Messaging can eliminate waiting time for communication to start. Studies show that this can be approximately 50% of the time devoted to traditional radio and telephone communication time (telephone availability, busy line, waiting in the inbound que, unavailable party, technical malfunction, etc.).

iv. Eliminates calls for loads (check calls).

v. Eliminates routine call-ins.

vi. Decreases wasted communication time due to misunderstandings, transcription and transposition errors, etc.

(3) Layover pay and expense reduction. Full-time tracking and control of linehaul units can improve fleet positioning in response to changing customer requirements and seasonal business. This can enhance driver/team productivity and utilization, and in turn reduces layover pay and associated expenses (motel rooms, meals, etc.).

(4) Dispatcher Productivity. Automating routine communication and dispatch functions allows more time for management and decision-making. Cost savings can result from fewer dispatcher hours spent on routine and time-consuming clerical tasks.

(5) Security, Safety, and Insurance. Position location and progress reports can be made as frequently as desired. Security and safety are improved with full-time communications. This should help reduce claims and insurance premium expenses. Routine periodic call-ins by telephone, with the added risks of "fender benders" while parking, cargo security difficulties, and possible driver exposure at some truck stops to drugs, alcohol, and prostitution are reduced. Emergency calls and position location can be provided in the event of hijack, accident or breakdown. Types of cargo insurance and self-insurance cost savings include:

i. Hazardous Materials.

ii. Explosives.

iii. Reduction in manpower required for armed guard service and constant surveillance shipments.

iv. Remote alarms for high/low temperature, severe shock, and unauthorized cargo access.

(6) Maintenance Expenses and Vehicle Operation Monitoring--Reduction in the requirement to make frequent communications stops can improve fuel usage and reduce engine and break wear. Electronic sensors attached to the engine, speedometer and other vital systems can allow almost real-time monitoring of equipment and driver performance.

Ability to promptly notify dispatcher of breakdown, in any location, reduces time to await towing and repair. Total out-of-service time and delay in movement of customer freight is minimized.

(7) Avoided Cost of Capital--More efficient equipment utilization allows a reduced fleet size, or greater service capability with existing equipment. This can lower total capital outlay, financing and\or lease expenses.

(8) Fuel Tax Data Collection--Ability to track actual miles driven in each state allows accurate allocation of state fuel taxes. This can reduce the prospect of carriers receiving adverse audit opinions from state fuel tax auditors.

(9) Trailer Location Devices--For companies which have a trailer-to-tractor ratio of greater than 1:1, productivity may be increased through a system which automatically identifies each trailer. Communication equipment in each tractor would automatically relay this information when picking up or dropping off a trailer. A computer system could be used to automatically maintain a position and status inventory of each trailer.

(10) Road, Weather, and International Border Crossing Advisories--Provides advance information to enable the driver to deal with contingencies and make alternate plans.

(11) Navigation Assistance and Directional Guidance--Computer system could perform route planning and scheduling based on automated position input.

c. Reduction of Administrative Expenses

(1) Full-time communication capability can streamline or eliminate many routine administrative functions. Drivers can be contacted directly or though electronic mailboxes. This eliminates the need for administrative personnel to wait for a driver to contact them. Types of administrative cost savings include:

i. Cash advance authorizations and information.

ii. Driver and equipment logs.

iii. Payroll/paycheck computation input.

iv. Transmit billing information from the driver and print directly in the office.

v. Proof of pickup and delivery.

vi. Customer service shipment status information.

vii. Personal message handling.

viii. Direct input into electronic data interchange (EDI) systems.

ix. Facsimile transmission of documents.

x. Expedite claim processing and status.

(2) Telecommunication Expense Reduction. Types of telecommunications cost-saving opportunities include:

i. Automated electronic mailboxes.

ii. Calls for loads (check calls) are no longer required.

iii. Routine periodic call-ins are no longer required.

iv. Non-contact communication delays are eliminated.

v. Total connection time is reduced (speed of digital data transmission versus voice).

vi. Number of inbound WATS lines are reduced.

d. Driver Retention and Pay--Driver retention may be increased with the professional prestige of driving an equipped vehicle and by allowing use of personal messaging via electronic mailboxes. The income of drivers paid on a per-mile basis can also increase because of the reduced need for communication stops. Less time spent making check calls enables more miles to be driven. Increased retention reduces training and administrative costs, and lessens the chance that trucks will be abandoned enroute.

e. Freight Broker Use--Use of nationwide tracking and communication terminals may enable a more efficient freight brokerage market. Independent drivers could procure terminals and authorize service providers to

forward position data and provide communications with selected brokers. Brokers would be able to make more efficient and timely load announcements and assignments based on carrier location, desired destination, and other requirements.

3. Other Potential Uses

a. Nautical and Inland Waterways

(1) Return relay of the ship's position calculated from satellite ranging would provide an additional aid to navigation.

(2) Organization management.

i. Long range communication with headquarters and operations.

ii. Real-time remote display of ship's track and position at headquarters could aid storm avoidance, route planning, schedule and port-of-call changes.

iii. Additional communications link with the operations center.

(3) Monitoring locations of key aids to navigation.

(4) Vessel traffic services monitoring.

(5) Monitor compliance with fishing treaties and economic zones.

b. Railroads

(1) Precision location of individual cars in rail yards.

(2) High\low temperature, shock, and unauthorized cargo access alarms.

(3) Inputs of train location, equipment status and operation data to automated railroad management systems.

(4) Communication with dispatcher.

c. Aeronautical

(1) Satellite air route traffic surveillance and control, particularly over open ocean areas.

(2) Air crew and passenger communications.

d. Emergency Services

(1) Emergency signaling and location reporting. Silent alarm could aid in theft recovery.

(2) Remote display of aircraft, land vehicle, and ship positions could facilitate search and rescue.

(3) Replace expensive leased telephone lines for burglar and fire alarms. Computer at the system network management facility would be programmed to automatically contact the appropriate authorities and pass the information via voice synthesis or digital means. User charges could be based on a low-cost annual subscription or per-use charge instead of a monthly rate.

(4) Require carriers hauling exceptionally hazardous commodities to have a terminal capable of continuous communications and position reporting. The terminal would be tied into both the company and into a centralized nationwide hazardous materials tracking and control center. This center would monitor shipment movements. If the driver signaled an emergency, was behind schedule, or was off of a designated hazardous material transport route, a computerized data base could be accessed to notify local authorities.

(5) Database access for hazardous materials.

d. Telemetry

(1) Remote site machinery status and control.

(2) Weather balloon and remote site data.

(3) Clandestine\law enforcement remote tracking.

(4) Environmental monitoring.

e. News Gathering.

f. Portable computer networking where telephones are not available.

g. Oil and Mineral Exploration.

h. Potential Military Applications for Secure RDSS and MSS.

   (1) Battlefield management.

   (2) Monitor mobilization progress.

   (3) Fleet management of tanks, trucks, jeeps etc.

   (4) Logistics planning and execution.

   (5) Incorporation of a separate and secure military RDSS or MSS type of system into "smart" reconnaissance drones and weapons could be used to remotely monitor location and flight path. This would allow non-radar tracking and real-time control when over the horizon or in enemy territory. Remote command capabilities would enable flight path and targeting changes, disarm and self-destruct contingencies. The use of high-speed spread spectrum burst transmissions would make enemy tracking and jamming more difficult.

E. CONCLUSION

The uses of regional and nationwide mobile communication technologies are by no means restricted to those listed above. The networking of terrestrial systems and the emerging capabilities of small, low-cost satellite terminals which permit mobile and portable communications from almost anywhere on Earth will undoubtedly will lead to a multitude of other applications. The emerging universal communications capability stemming from increased miniaturization and sophistication of mobile communications systems seems to further confirm Marshall McLuhan's concept of the "global

village," where space and time between East and West becomes that of a hamlet [Ref. 5].

II. OVERVIEW OF MOBILE COMMUNICATIONS SYSTEMS

A. INTRODUCTION

This chapter provides a basic description of systems which can provide public land mobile communications on a local, regional, or nationwide basis within the U.S. Each of these systems are presently in operation or have been authorized to provide service by the FCC. A more detailed description of existing and proposed satellite systems which can provide coverage of North America is provided in Appendix A. Appendix B contains an overview of communication, satellite, and navigation concepts for readers who require additional background.

The mobile communication technologies discussed below are constantly undergoing technological improvement and exist in a highly dynamic economic and regulatory environment. Although accurate at the time this thesis was written, readers are urged to verify operating details and costs when evaluating systems.

B. RADIO DETERMINATION SATELLITE AND MOBILE SATELLITE SYSTEMS

1. Common Architecture

Existing and planned systems have several elements in common.

a. User Terminals

In most cases user terminals are mobile or transportable, although in some applications terminals will be fixed. Widespread use of satellite services requires that terminals be affordable. The general goal is to keep the purchase price low through simplified design and reduced transmitter power. Technical complexity is generally concentrated in the satellite and the network management facilities.

User terminals consist of a keyboard display unit, associated transmit and receive electronics, and one or more antennas. Terminals are capable of using preprogrammed message macros to make it easier for the user to send messages and reduce transmission length and system loading. Terminals also have the capability of sending data that are collected by remote sensors, such as refrigerator temperature and vehicle speed.

b. Ground Facilities

Each organization uses ground station equipment to govern the system operation and interface between the satellite and user control points. These facilities have different names depending on the system. Geostar and Qualcomm call this the network management facility (NMF), while it is termed the network control center (NCC) by the U.S. and Canadian mobile satellite system.

These facilities consist of an earth station and satellite modems for communications with mobile terminals, a network management computer (NMC), and equipment for connection to the telephone system, packet switched networks, and very small aperture terminal (VSAT) satellite networks. The NMC performs message management, location determination, customer billing, and other functions. The NMC generally acts as an electronic mailbox, storing and forwarding information on a periodic basis, or providing real-time delivery over dedicated communication circuits.

c. User Control Point

The user control point consists of a computer (PC, mini, or mainframe) running communications, data base, and vehicle position display software. Connection between the user control point and NMF is variable based on volume of communications and the need for real-time data. Continuous communications can be maintained through VSAT satellite communication links, packet-switched networks, or leased telephone lines. Periodic communications can be made by automatic dial-up from a computer equipped with a 1200 baud or higher speed modem.

d. Satellite

In currently authorized systems, the satellite acts as a "bent pipe" to relay communications between mobile terminals and the NMF. Future satellites with a higher degree

of sophistication will perform on board message processing, switching and routing.

e. Position Determination

User position is determined in two different ways. Mobile satellite systems utilize regional and worldwide navigation receivers (Loran-C, Transit, and GPS) which are incorporated into the user terminal. The terminal's internally calculated location is relayed to the NMF along with any other data communication. Radio determination satellite systems (RDSS) use a constellation of two or more geostationary satellites to determine position through ranging.

2. Geostar System 2.0

As shown in Figure 2, this one-way L-band MDS system uses receiver packages located aboard the GTE Spacenet III and GTE GSTAR III satellites for communications relay. The mobile terminal contains a keyboard for message input and an integrated Loran-C navigation receiver. The terminal can be programmed to automatically send location information, and is usually set to transmit once an hour. Location data are also transmitted each time the user sends a keyboard message. Maximum message length per packet is 97 characters. Longer messages may be sent by linking packets. Loran-C location accuracy is typically a mile or less, although in the Southwestern portion of the U.S. where coverage is not as good, the accuracy is typically within five miles.

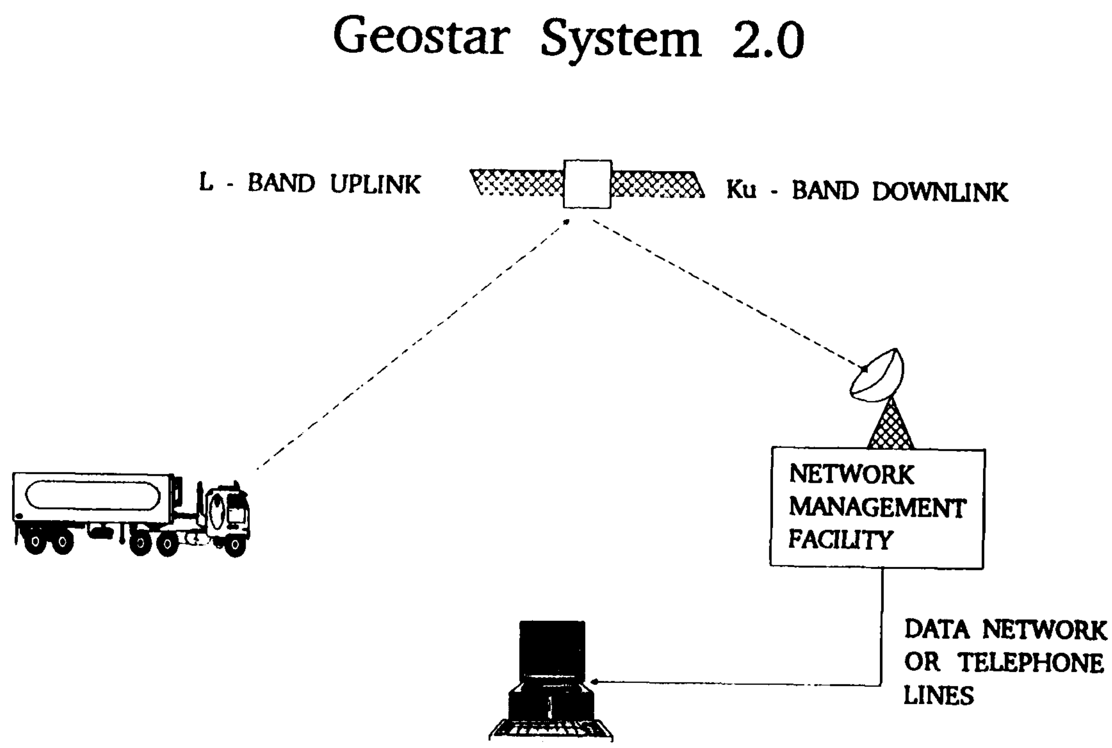

Figure 2. Geostar System 2.0

Capacity of the system is estimated to be up to one million subscribers. Total capital expenditures for System 2.0 are estimated at between $50 and $60 million [Ref. 1:p. 35]. Minimum monthly service charges are $45, which allows slightly more than one transmission per hour from the vehicle to the NMF (approximately 900 per month). Additional transmissions are priced at five cents each. Cost for the mobile terminals, manufactured by Sony and Hughes Network Systems, are approximately $3300. To utilize the Geostar system, an Apple Macintosh or IBM compatible PC and software costing approximately $3000 are required. Application software is also available for mini and mainframe computers.[1]

The major limitation of System 2.0 is its one-way nature. Dispatchers can track their vehicles and receive inbound messages, but they can not contact their drivers. Because no acknowledgement of message receipt is possible, drivers can not be advised when their messages are not received. However, the probability of the NMF receiving the message is increased by repeating the transmission several times.

3. Geostar System 2.0 and Nationwide Pager

To help overcome the one-way limitation of System 2.0, a nationwide pager can be used to relay communication from the dispatcher to the driver. However, nationwide pagers do not

[1]Telephone conversation between Mr. Nick Cheston, Geostar Corp., and the author, 21 June 1989.

provide uninterrupted coverage and are restricted to the more densely populated areas. Nationwide pagers are discussed in more detail below.

4. Geostar System 2C

To provide uninterrupted two-way nationwide coverage, Geostar has leased a C-band transponder on the GTE Spacenet III satellite. As illustrated in Figure 3, the inbound path between the vehicle and the NMF flows through a System 2.0 receive-only satellite package, while the outbound path is relayed via the C-band transponder. Communication system logic acknowledges message receipt and provides for retransmission as necessary. Geostar 2C service capability was implemented in the summer of 1989.

To upgrade to 2C, existing one-way equipment is connected by cables to a C-band receiver package. Antenna configuration is also changed. Costs to upgrade existing transmit-only packages are approximately $1800, and complete System 2C transceivers are priced at approximately $4100.

The maximum outbound message length per packet from the NMF to the mobile unit is 128 characters. Outbound data is transmitted at 1200 bits per second. At 50 characters per message, the physical capacity of a single 2C system transponder is approximately 10,800 messages per hour. The C-band link could support about 40,000 to 50,000 users if base stations on the average send a message to mobile terminals approximately once every four or five hours. Additional

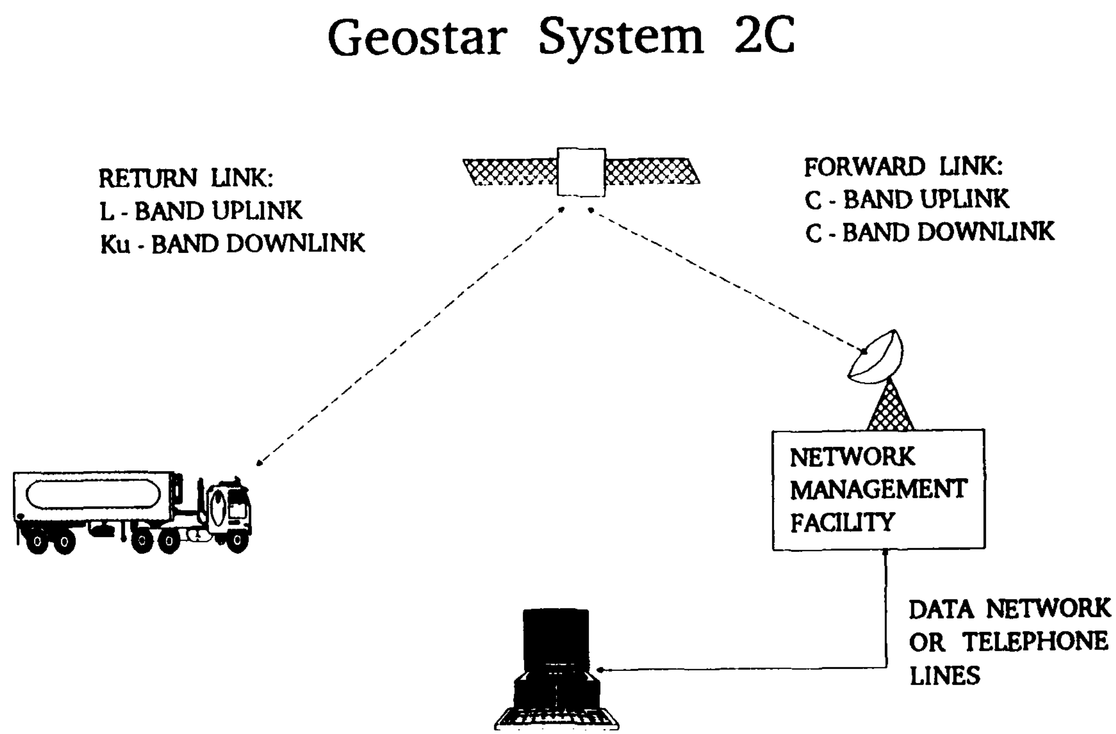

Figure 3. Geostar System 2C

transponders may be leased to compensate for increased message loading.[2] Actual costs for the lease of a C-band transponder are proprietary, but protected C-band transponders are available for about $125,000 per month on a three to five year lease. The FCC has authorized the initial operation of up to 20,000 2C receiver units [Ref. 6].

5. Geostar System 3.0

System 3.0 is the L and S-band RDSS configuration envisioned in the FCC license, and is scheduled for implementation starting in 1992. Ultimately, the orbiting of three dedicated RDSS satellites is planned. These satellites will use multiple spot beams and high speed spread spectrum transmissions to handle between five and ten million messages per hour. The on orbit cost of each satellite is expected to range from $75 million to $125 million (which includes the construction of the satellite, launch, and insurance). Ground facility expenses could raise the cost of the system as high as $400 million.[3] Terminal position will be determined through the use of satellite ranging.

System 3.0 operation is shown in Figure 4. The NMF repeatedly broadcasts a general interrogation message to all users, requesting if any unit wants to transmit. At the end

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[2]Telephone conversation between Mr. Nick Cheston, Geostar Corp., and the author, 21 June 1989.

[3]Telephone conversation between Mr. Victor Silvera, Geostar Corp., and the author, 4 May 1988.

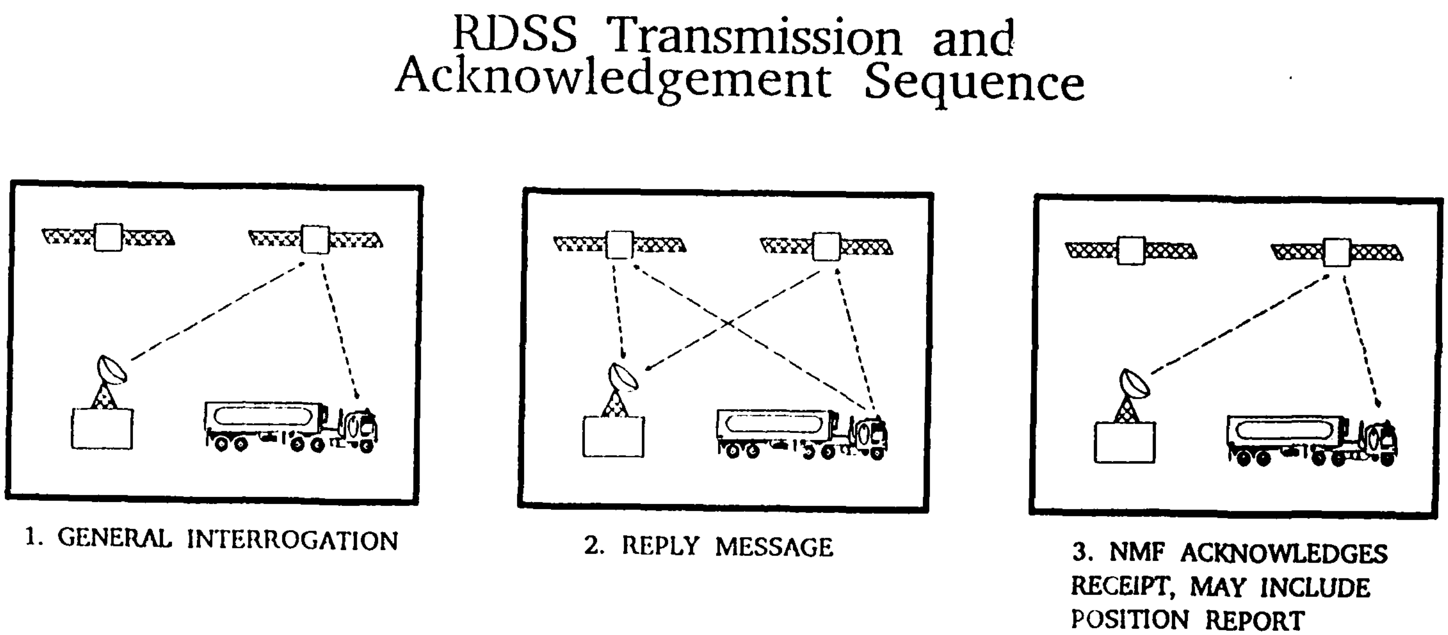

Figure 4. RDSS Transmission and Acknowledgement Sequence

of a preset time period or at operator command, the terminal unit will respond with its unique identification code and any message. This transmission is relayed via two or more satellites to the NMF computer. The computer determines the difference in arrival times of the signal, and calculates the transmitter's position. The content of the message is decoded and routed to the proper electronic address. The computer also sends an acknowledgement back to the transceiver. If any acknowledgements are missed, the mobile transceiver or NMF will retransmit as necessary. Message length in both directions is 97 characters. Positioning accuracy is less than 50 meters [Ref. 8:pp. 39-59].

6. Qualcomm OmniTRACS

As shown in Figure 5, the OmniTRACS satellite mobile data system uses two existing Ku-Band satellite transponders for full two-way communications services. Depending on the configuration of the terminal, positioning information is determined through an integrated Loran-C receiver or satellite ranging using a second satellite. Messages can be up to 2000 characters long. Mobile terminals range in cost from $4100 to $4500, depending on volume. Monthly service charges are $35 for hourly positioning, plus $0.05 per text message and $0.002 per character.[4]

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[4]Interview between Mr. Bob Carr, Qualcomm Inc., and the author, 12 April 1989.

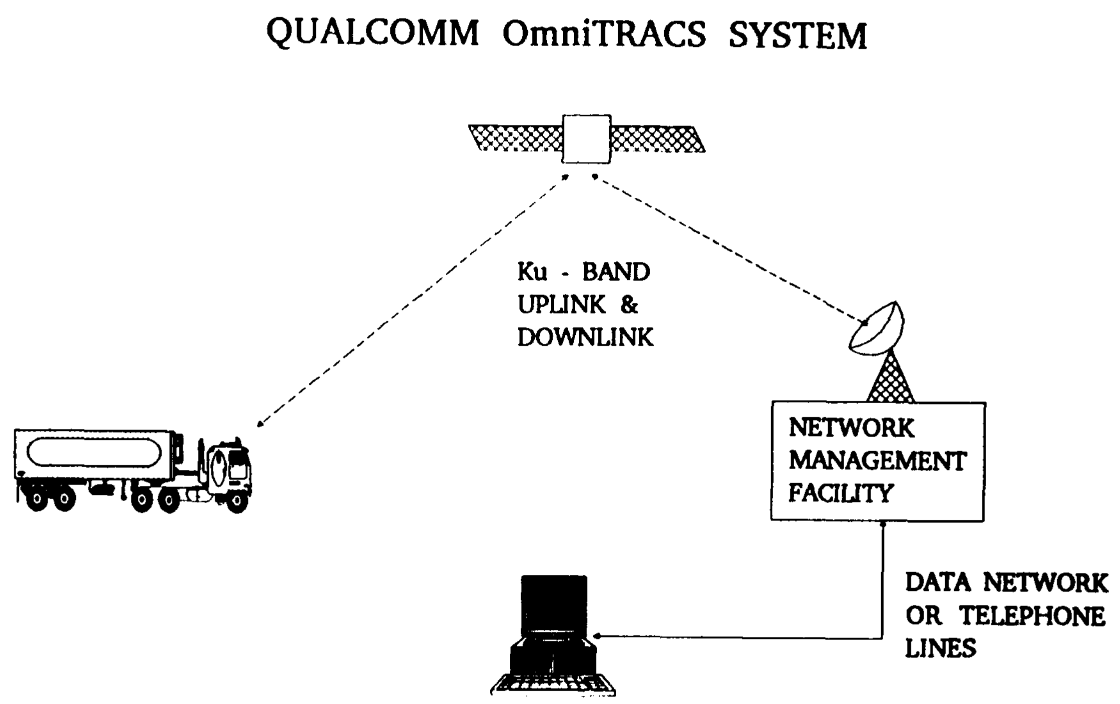

Figure 5. Qualcomm OmniTRACS System

Depending on the average message length and frequency of transmission, system capacity is approximately 40,000 to 60,000 users per transponder pair.[5] The FCC initially authorized the operation of 20,600 terminals [Ref. 7]. Qualcomm can apply for additional authorizations should the need arise. If the system approaches physical saturation, it can be enlarged by obtaining additional terminal authorizations and leasing more transponders. By leasing transponders on a long-term basis, Qualcomm has avoided the large capital costs and risks associated with launching satellite hardware. Although exact lease expenses are proprietary information, protected Ku-Band transponders on U.S. satellites can be acquired for approximately $155,000 a month on a five year lease.[6] The net present value of two transponders over five years at a 12% cost of capital is approximately $13.9 million.

The OmniTRACS system has been operating in the U.S. under FCC licence since February 1989. The system is now operating in Europe on a pair of EUTELSAT Ku-band transponders. Negotiations were taking place in September 1989 to provide OmniTRACS service in Japan, and tests in Australia are expected in mid-1990. [Ref. 9]

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[5]Speech by Dr. Andrew Viterbi, Qualcomm Inc, at the Phillips Publishing Mobile Satellite Conference, Washington, D.C., 6 November 1989.

[6]Telephone conversation between Ms. Grace Leone, EFS Satellite Services, and the author, 4 April 1990.

7. American Mobile Satellite Corporation and Telesat Mobile Satellite System

a. Background

The American Mobile Satellite Corporation (AMSC) and Telesat Mobile Incorporated (TMI) have been authorized by their respective regulatory agencies to provide Mobile Satellite Service (MSS). For initial service, AMSC and Telesat Mobile have agreed to jointly procure two satellites, one for each company, and to cooperate on the definition of compatible systems. This eliminates the need for either company to have a costly, in-orbit spare satellite and permits production economies of scale for space, ground, and mobile equipment. [Ref. 10]

In addition to data, the MSS system will provide a variety of analog and digital voice services. Navigation receivers such as Loran-C and GPS can be incorporated into user terminals to provide remote tracking capability. AMSC has been authorized to service the following markets:

a. telephone service (MTS)--voice communications interconnecting mobile land vehicles, boats or aircraft and the public switched telephone network.

b. mobile radio service (MRS)--a two-way voice dispatch service between a user terminal and a base station.

c. mobile data service (MDS)--two-way data communications that may be combined with MTS or MRS.

d. aeronautical service--voice and data communications for safety and other purposes including:

    (1) air traffic control (ATC)--communications related to safety and regularity of flight;

(2) aircraft operational communications (AOC)--flight management communications between the aircraft and ground facilities;

(3) airline administrative communications (AAC)--communications to improve airline customer services;

(4) airline passenger communications (APC)--commercial voice and data passenger communications.

e. transportable service--telephone and two-way data communications to users in sparsely populated areas using portable terminals at fixed locations.

f. paging service--one-way communications on a non-interference basis. [Ref. 11]

b. System Configuration

The first of three authorized AMSC satellites is planned to be operating in late 1993 or early 1994 [Ref. 12]. Coverage of North America will be by eight L-band spot beams and one Ku-band beam. Each satellite has a design life of 10-12 years [Ref. 13:Part II, pp. 17-23].

Figure 6 illustrates the basics of the MSS system [Ref. 13:Part I, p. 16]. Mobile and fixed terminals will transmit and receive on L-band frequencies. Uplinks and downlinks between the satellite, gateway stations, and feeder-link stations will be at the Ku-band. The system is controlled by a network control center (NCC). The system shares part of the spectrum with the aeronautical mobile users. Within the aeronautical spectrum the NCC assigns channels to users based on priority, with emergency services and aircraft receiving the highest precedence. The system is connected to the public switched telephone network (PSTN) and

AMSC & TMI Mobile Satellite System

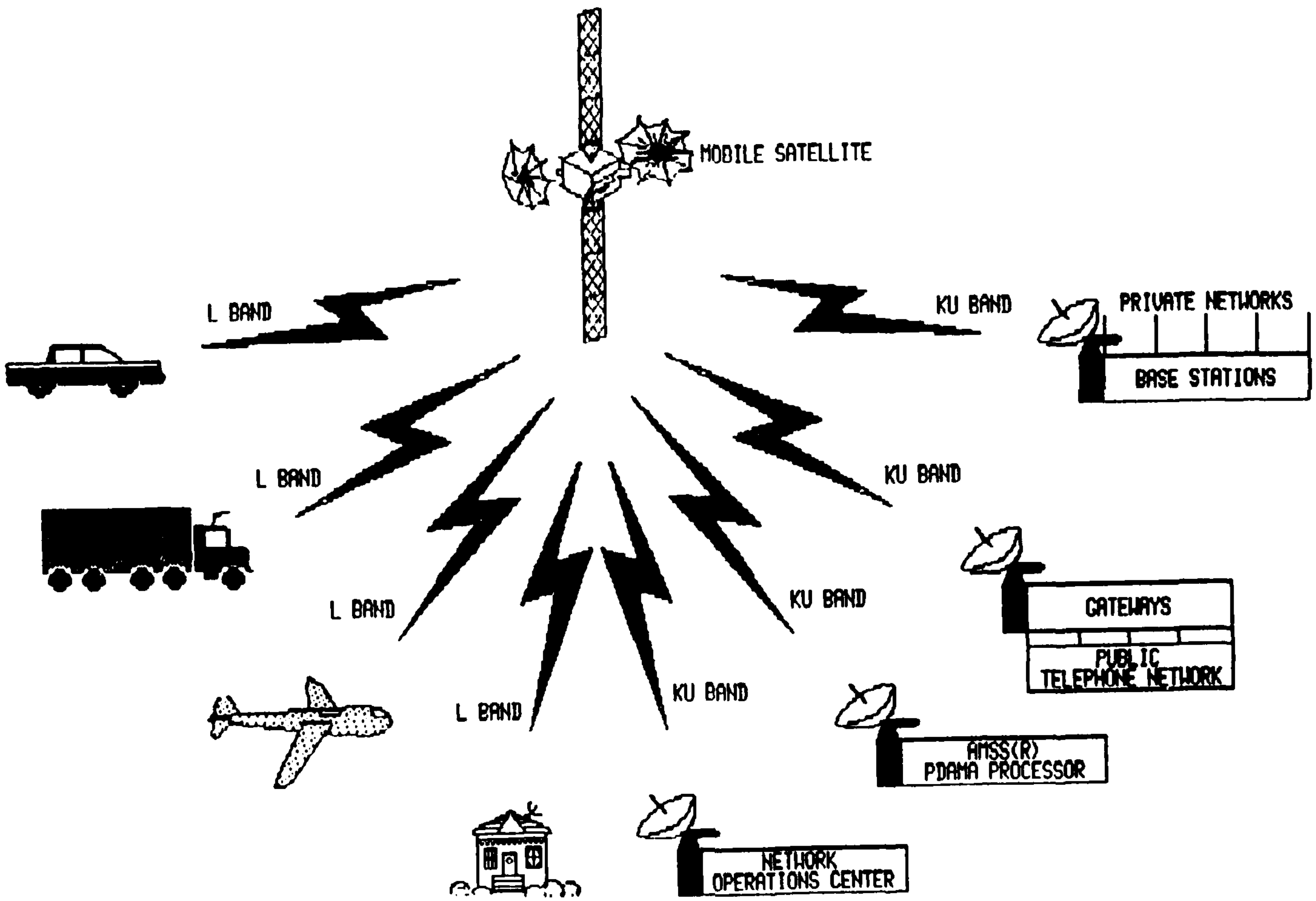

Figure 6. AMSC and TMI Mobile Satellite System

data communication networks by gateways located throughout the country. Connection with private networks will be via simpler earth stations designated as feeder-link base stations.

c. System Operation

Any mobile, gateway, or feeder-link base station requesting service will communicate with the NCC over a common data channel. On initial power-up, mobile terminals perform all necessary handshakes with the NCC for identification and to receive authorization as a valid subscriber. The initial handshake also serves to identify the terminal's location and spot beam. Based on priority of use, the NCC will dynamically assign communication channels. For mobile telephone service, a pair of channels will be assigned to allow both parties to transmit and receive simultaneously (full duplex). The NCC will automatically route calls through the closest gateway to minimize the total communication costs. Since by design the satellites will not convert from one L-band channel to a second, calls between mobile terminals will require two satellite hops via a gateway or base station [Ref. 14:pp. 152-156]. This type of traffic usually operates in a mobile radio environment with push-to-talk microphone operation, so the time lag associated with two hops should not be a problem.

d. Costs and Revenues

Under the MSS license, the FCC will regulate AMSC as a common carrier in the space segment. The ground segment will be open to multiple service providers, and subject to

competition. AMSC will be a "wholesaler," billing service providers for satellite time. Service providers in turn will charge customers for the total space and terrestrial service [Ref. 13:pp. 26-27]. In Canada, TMI will provide air-time and be a ground-segment provider through their national system organization.

In its 1988 filing with the FCC, AMSC estimated the total cost for the MSS system to be $730 million. Revenue projections for the space segment over a 16 year period, adjusted for inflation, were forecast to be $2.45 billion, with total operating expenses and depreciation estimated to be $900 million. Revenue projections were determined by multiplying the anticipated demand for each of the services by their respective projected prices. Beyond the fifth year of service revenues were limited by satellite capacity. [Ref. 13:pp. 31-34]

The ultimate AMSC tariff will depend on the bandwidth and the power of the channel or channels used, since these are the factors ultimately effecting satellite capacity. In addition, the tariff can be expected to reflect the time of day, call duration, priority access, length of commitment for services, and value-added services. [Ref. 13:p. 26]

As outlined in the 1987 FCC filing, the weighted average price for all space segment communications was determined to be 52 cents a minute. For mobile telephone service, AMSC estimated that an additional charge of 20 cents

per minute would be added for the ground communication segment. This assumes that PSTN gateways are reasonably well distributed so the terrestrial communication distance is short. Adding ten cents per minute to cover expenses such as sales and marketing brings the total to about 82 cents per minute, or about $82 per month for 100 minutes of service [Ref. 12:p. 27]. Data packets will be 256 bits long and forecast to cost two cents each. AMSC estimates the average inbound message will be ten packets long and cost 20 cents. Average outbound messages will be consist of 20 packets and cost 40 cents [Ref. 13:p. 45]. Mobile user terminals are expected to cost between $1500 and $3500 when produced in large quantities [Ref. 12:p. 27]. The user should adjust these quoted figures for inflation and other uncertainties associated with making cost forecasts six years in advance.

e. AMSC and Telesat Mobile Early-entry Mobile Data Service

AMSC and TMI are developing a phase one mobile data service which will be operational by mid 1990 using L-band space segment capacity leased from the International Maritime Satellite Organization (INMARSAT). Plans call for the relocation of an older maritime communication satellites (MARISAT) to provide for improved North American coverage. Terminals will be upwardly compatible with the AMSC and Telesat satellites. Digital terminals are expected to cost

around $4300 U.S., and communication charges are expected to be similar to Geostar System IIC and Qualcomm rates.[7]

C. U.S. GOVERNMENT TRACKING SYSTEM

The U.S. Government operates a nationwide vehicle tracking and communication system known as SECOM III. This system is used to monitor the position and status of vehicles carrying classified or hazardous cargoes. Figure 7 illustrates this system.

1. System Configuration

The mobile system consists of a Transit satellite receiver, dead-reckoning equipment, and a high-frequency (HF) transceiver (combined transmitter and receiver). Communication to and from the network management facility (NMF) is by encrypted voice and keyboard input.

a. Position Determination

Transit satellites do not provide continuous coverage and position data because they are in a low altitude orbit. Dead-reckoning equipment is used to provide estimated positions when Transit satellites are not available. Dead-reckoning equipment uses direction and speed inputs to periodically calculate the vehicle's location. Each change of direction and speed introduces a small error into the computed position. These errors are cumulative and the estimated

[7]Telephone conversation between Mr. Orest Roscoe, General Manager of Network Development, TMI, and the author, 24 August 1989.

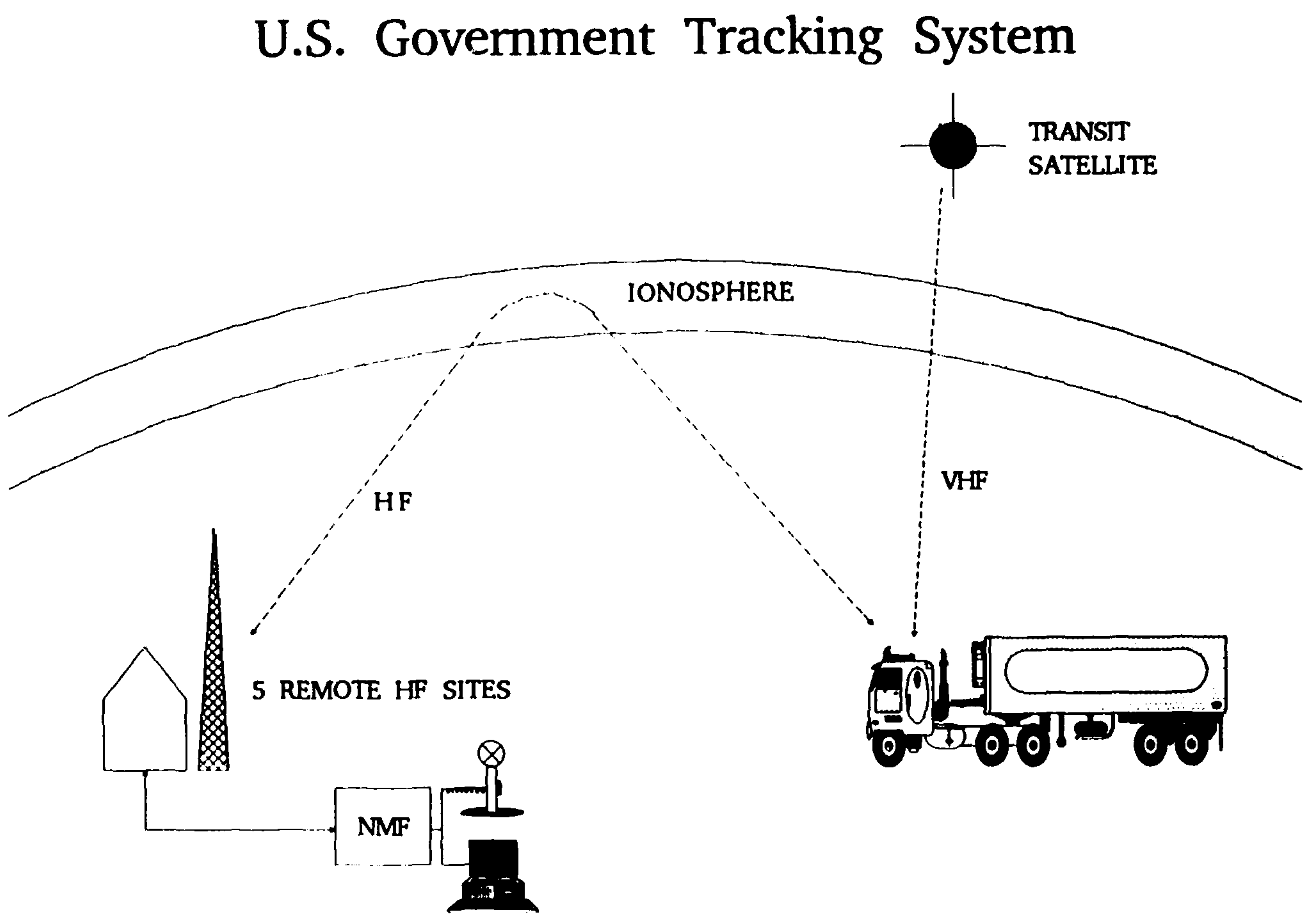

Figure 7. U.S. Government Tracking System

position of the vehicle degrades over time. With each Transit Satellite pass the actual location of the vehicle is determined and the dead-reckoning position is automatically corrected.

b. HF Communication Link

This system was implemented before mobile satellite communication was available, and HF was the only way to economically provide continent-wide communications coverage. Five HF stations around the country are used to ensure reception and system redundancy. The HF frequencies and sites with the best reception are automatically selected for use with a given mobile unit.

c. Network Management Facility (NMF)

The remote HF sites are tied into the NMF via leased telephone lines. NMF computers control communications and display vehicle position information are overlaid on digitized maps. The maps can be displayed at zoom levels down to a scale of 100,000 to 1 (approximately 1.6 miles per inch or one Kilometer per centimeter). The computers also maintain various data bases for tracking equipment, personnel status, and miscellaneous other information.

2. System Strengths and Limitations

This system was assembled for far less than it would have cost for a dedicated geostationary satellite system. SECOM III capacity, in relation to satellite-based systems, is limited due to the small number of allocated HF frequencies,

the HF transmission modes, and the number of times per hour each unit is required to transmit its position. Leased long distance telephone lines are a major operating expense. The system would not be commercially viable because of the large investment costs and monthly operating expenses per serviced mobile unit. However, it is cost justifiable for security and safety applications.

Since SECOM III is under government control, it is less vulnerable to disruption than commercial systems. Planned improvements include the replacement of Transit receivers with GPS and a custom optical disk U.S. data base. Computer mapping displays will be updated at approximately one minute intervals and be commensurate with GPS positioning accuracy.[8]

D. METEOR BURST COMMUNICATIONS

1. Background

Meteor-burst communication works by reflecting radio waves off the ionized trails left by meteors as they disintegrate in the atmosphere. Research on meteor burst was done in the 1950's. The advent of satellite communications in the early 1960's undercut the interest in meteor burst because satellites seemed to fulfill the need for reliable, instantaneous communications over long distances.

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[8]Telephone conversations and interview with Mr. Roy Martinez, Proteus Corp., and the author, between February and June 1988.

The use of meteor burst for land-mobile communications is a new application. Until recently, meteor burst was used only from fixed sites. Since 1978, the U.S. Department of Agriculture's Snotel system has used meteor burst to relay snow cover, temperatures, and river level data from about 550 remote sensors in the Rocky Mountains. In Alaska, meteor burst is used by the Air Force for remote pipeline monitoring, and for obtaining remote weather data at isolated airstrips. [Ref. 15:pp 1-2]

2. Theory

Billions of particles ranging in size from dust to sand grains enter the atmosphere every day. Their kinetic energy is enough to ionize a column of air up to 12 miles long at an altitude of between 50 and 70 miles. Although these small meteor particles disintegrate almost instantaneously and never reach the ground, their ionized trail will persist from a fraction of a second up to several seconds. This is long enough to reflect brief radio transmissions.

The length of time that a meteor trail is capable of reflecting radio waves is dependant on the radio frequency, with lower frequencies persisting longest. For this reason, operating above the HF band in the low VHF frequency region (between 30 and 50 MHz) is considered to be the best for meteor burst communication. The maximum distance a single meteor burst signal can travel is approximately 1200 miles, and is a function of the meteor trail height and the curvature

of the earth [Ref. 1:p. 39]. A signal returned to the ground by a meteor trail will cover an elliptical area about 15 miles by 30 miles.[9]

The amount of meteors entering the atmosphere is variable. The early morning hours around dawn are the most productive because the Earth's orbital movement sweeps up incoming meteors and the Earth's Easterly rotation also adds to their apparent velocity. Time of year, or position of the Earth along its orbit, also affects the meteor count. The Earth's 23.5 degree tilt causes different regions to be "in front" of the Earth as it moves through space, thus hitting more meteors. The Earth also periodically passes through relatively dense streams of particles, thought to be the remnants of a comets, that are in elliptical orbit around the Sun. [Ref. 16:Ch. 22 p. 15]. These factors combine to cause wait times between transmissions on a specific communication path to vary from a few seconds up to 15 minutes.[10]

To determine when it is possible to communicate over a specific path, the master station continuously broadcasts a "probe" signal. When this signal is received by a remote unit, a communication path exists. The remote unit must

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[9]Speech by Mr. James Feeney, President of Transtrack Corp., at the Munitions Carriers Conference, San Diego, Ca, 6 December 1989.

[10]Telephone conversation between Mr. Carlos Roberts, Vice President, Pegasus Message Corp., and the author, 17 August 1989.

immediately transmit a reply before the meteor trail disperses. This reply can contain either a previously-stored message or an acknowledgement that the probe was received. In either case, by receiving a reply message, the master station is informed that a communication path exists. If the master station holds a message for the mobile unit, it is immediately transmitted. The mobile station will then acknowledge receipt of the message.

The requirement for a rapid exchange of messages over a brief time period limits meteor-burst systems to high-speed data, and places an upward bound on message length during any one transmission. However, full-length messages can be represented by a one or two character code, leaving the remaining number of allowed characters for user input information. For example, a macro message represented by a single letter or number can convey 36 different messages. A combination of two alphanumeric symbols is capable of representing 1296 messages (36^2). Longer messages can also be broken up and transmitted one segment at a time.

Transmitters used in meteor burst need to have relatively high power (several hundred watts for mobiles and 1000 to 10,000 for base stations), and receivers must be very sensitive to enable continuous reception of data while the signal weakens from the vanishing meteor trail. Because meteor-burst systems use low-band VHF frequencies, much of the

hardware is conventional and low in cost. A Loran-C or GPS receiver can be used to provide position location information. Figure 8 illustrates a basic meteor burst system. [Ref. 1:pp. 39-42]

As shown in Figure 9, to cover the continental U.S. requires a network of five ground master stations, each covering a 500 to 700 mile radius. Underneath this umbrella, the denser metropolitan areas can be networked by using conventional low-band VHF repeaters. This can provide communications without a time delay and allows the use of the same transceiver.[11]

3. System Configuration and Operation

Transtrack Inc. (Marion, Ma) and Pegasus Message Corporation (Herndon, Va) are currently involved in mobile meteor-burst tracking and communications systems. Both currently have regional systems operating on the East Coast. Since Transtrack declined to provide any specific information, only the Pegasus system is described below.

Pegasus currently uses two master station sites located in Tennessee and Kentucky, giving coverage of approximately 50% of the U.S. A Kansas site is planned to be working by the end of 1989, bringing coverage of the U.S. up

[11]Telephone conversation between Mr. Carlos Roberts, Vice President, Pegasus Message Corp., and the author, 17 August 1989.

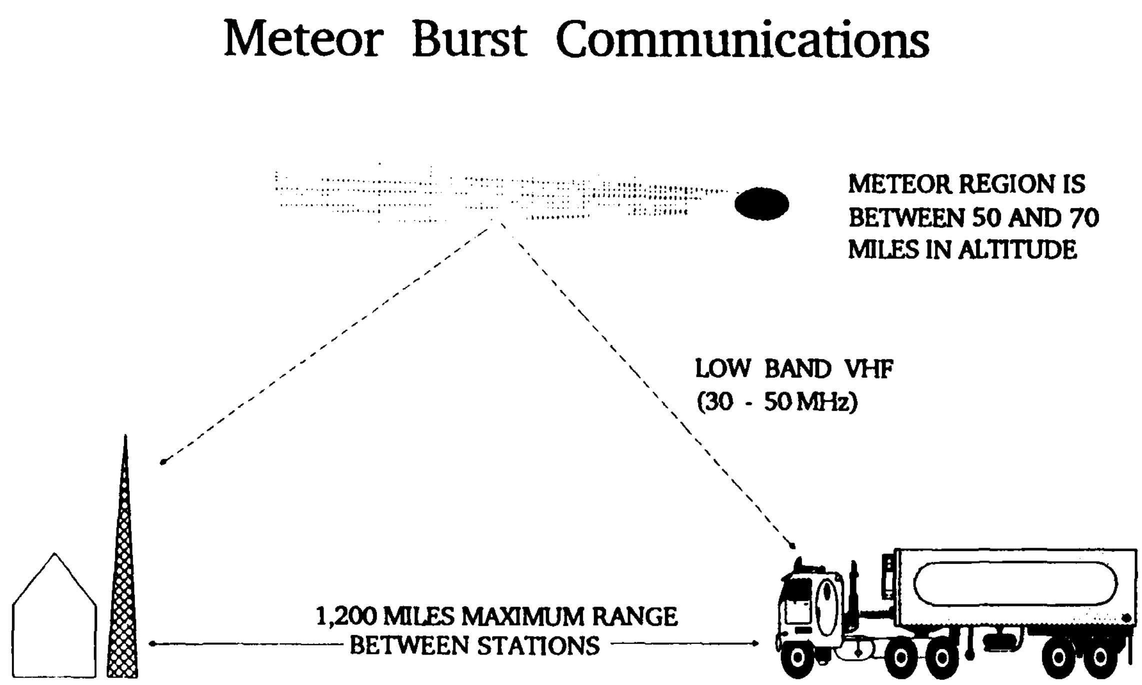

Figure 8. Meteor-Burst Communications

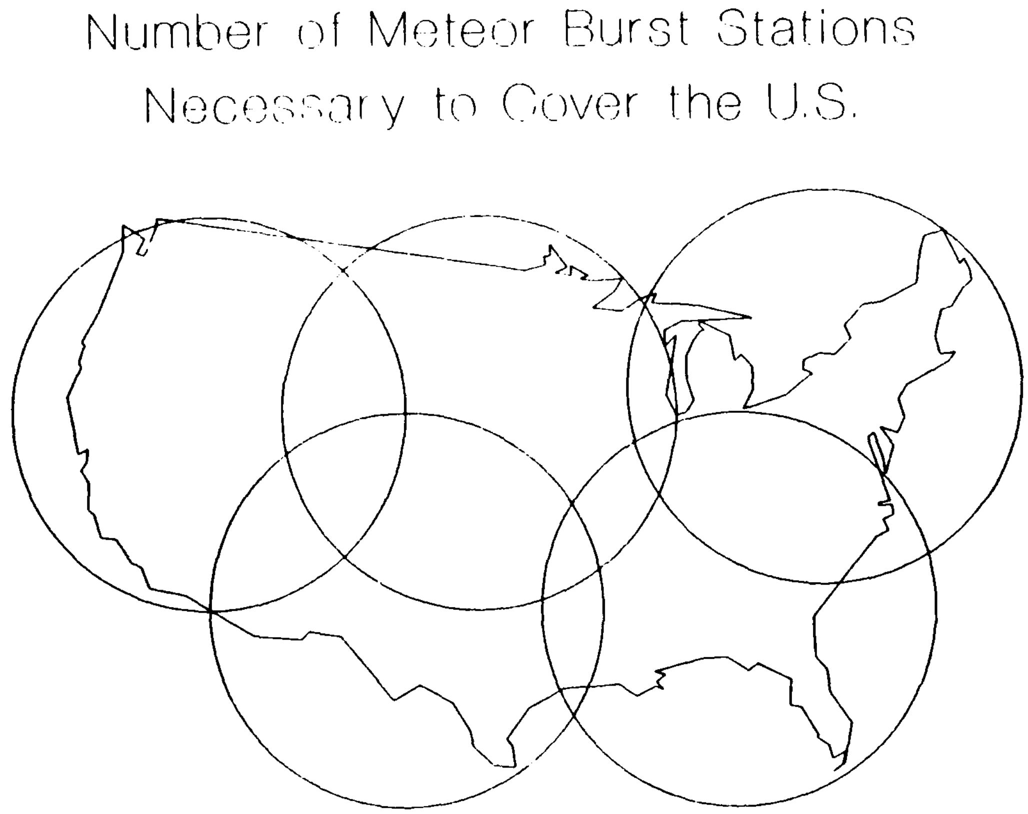

Figure 9. Number of Meteor-Burst Stations Necessary to Cover the U.S.

to about 80%. 100% coverage will be achieved when a West Coast station becomes operational in 1990.

The present master stations are connected to the NMF via a Ku-band VSAT, with leased telephone lines as a backup. Master stations continuously transmit at 49.595 MHz and receive on 47.005 MHz (full duplex). Each master station operates in one or more 45 degree sectors. Each sector has its own ten kilowatt transmitter, receiver, and antenna system. Master stations have complete backup equipment, power capabilities, and service coverage 24 hours a day.

Each mobile unit operates half-duplex, constantly listening for the probe signal except when it is transmitting to the NMC. The mobile transceiver has a maximum power output of 250 watts. A single 45-inch whip antenna is used for meteor-burst communication and Loran-C reception. The mobile transceiver keyboard display unit contains a 40 character by four line supertwist LCD display. Preprogrammed macro messages can be used to extend the effective length of the 16 character message size.

System protocol is proprietary and includes error correction. A collision-detection method is used to prevent errors in the event two or more trucks are in the same propagation path and attempt to transmit at the same time. The probability of this occurring is low, but could happen when trucks are grouped together, such as at a truck stop. Data are transmitted at 4800 baud. To increase communication

throughput, short messages from the dispatcher to the truck are included in the probe signal and are constantly retransmitted until the mobile unit acknowledges receipt. The Pegasus system is initially capable of supporting up to 50,000 mobile units, but can be expanded to 200,000 units. Outbound message delivery delay during February 10 through February 17, 1989 are illustrated in Figures 10 and 11. Pegasus is developing proprietary techniques to further reduce the average message delay. Actual cost for implementing a nationwide meteor-burst system is proprietary, but is estimated at between two and five million dollars. User costs are $35 per month for 24 position reports per day, plus $0.10 per message. Mobile transceivers are priced at $2500 each, and include the first $500 of communication charges. The effective cost of the transceiver is $2000.[12]

4. System Issues

Since meteor-burst systems use a medium that never needs replacement, there is no need to build an expensive system of satellites or an extensive ground-communications network. In contrast with dedicated mobile-satellite systems, master stations can be easily repaired and additional units of communication capacity added at a very low cost. Technological risk is minimal because most equipment is low-band VHF.

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[12]Telephone conversation between Mr. Carlos Roberts, Vice President, Pegasus Message Corp., and the author, 17 August 1989.

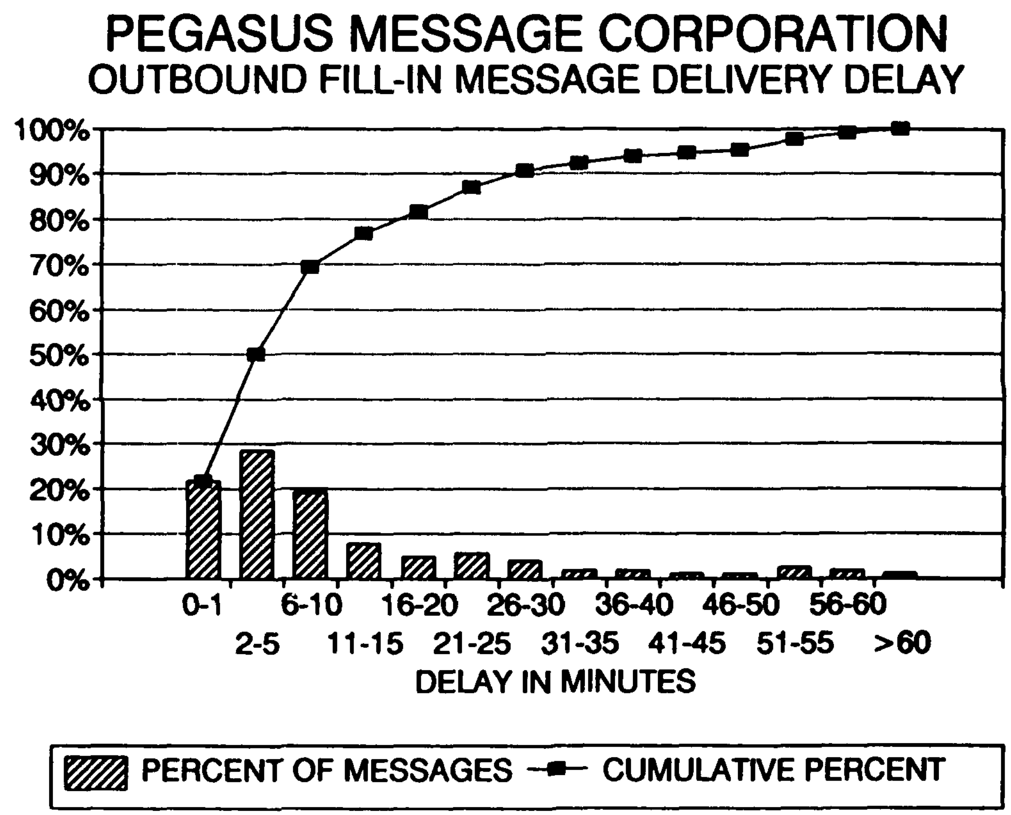

Figure 10. Pegasus Message Corporation Outbound Fill-In Message Delivery Delay

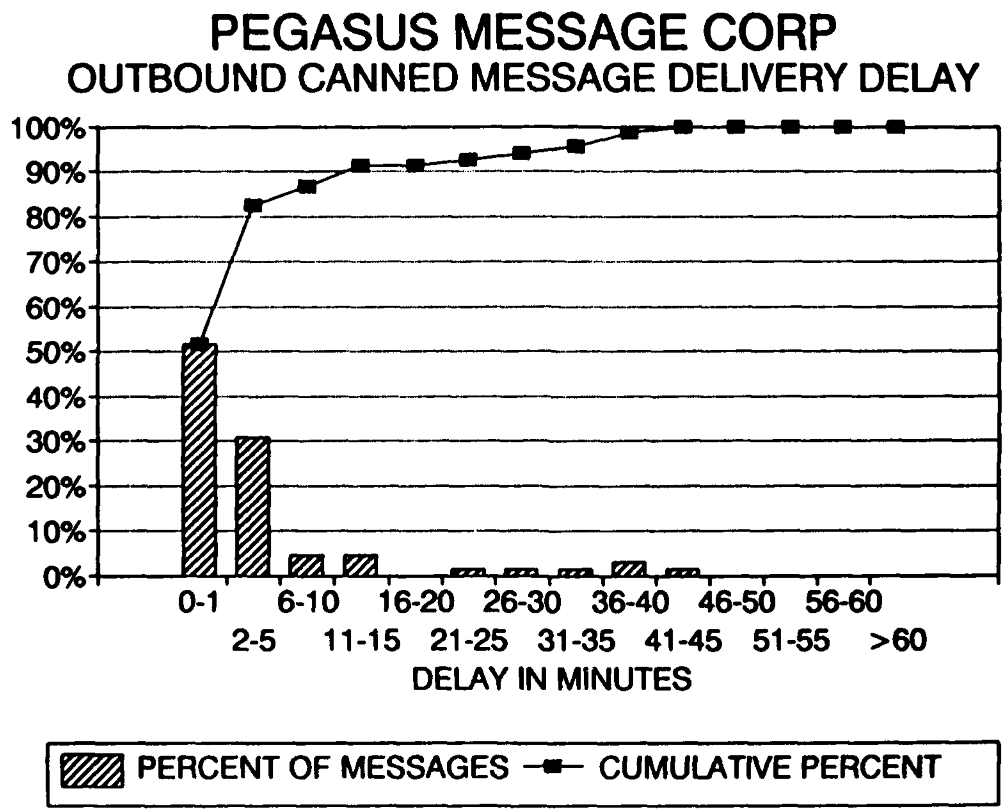

Figure 11. Pegasus Message Corporation Outbound Canned Message Delivery Delay

Mobile transceivers are available for $2000 in very small quantities, and with volume production will cost substantially less.

The 30 to 50 MHz frequencies used for meteor-burst transmissions bend around objects and penetrate trees to a far greater degree than L-band mobile satellite frequencies. Since there is no need to "see" a specific point in the sky, meteor-burst signals are less likely to be blocked by obstructions such as buildings or mountains. Meteor burst does not provide any geolocation capability and requires an external navigation source to obtain position information.

From a user's standpoint, the main objection to meteor-burst systems may be the variable waiting times between communications and the limited message length. However, when compared to currently operating satellite systems, meteor burst is cost favorable for those applications which require universal coverage, can use preprogrammed macro messages, and do not require virtually instantaneous message delivery.

E. CELLULAR RADIOTELEPHONE

1. Background

The original cellular radio design was developed by AT&T in the late 1960's and early 1970's to meet the communication needs of the largest U.S. metropolitan areas. The number of channels then assigned by the FCC for conventional, pre-cellular mobile telephone were inadequate to satisfy user

demand in densely populated markets [Ref. 17:p. 72]. Conventional mobile telephones were basically simple multi-channel transceivers which were connected to the telephone network by dialing mechanisms or mobile operator service.

2. System Configuration and Operation

To overcome these limitations, AT&T devised a system of frequency reuse, automatic switching, and trunking. The term "cellular" comes from subdividing a geographic area into smaller areas known as cells. Each cell has its own low-powered, low-height radio transmitter and receiver. This system, termed "reuse," permits the same frequency to be simultaneously used with a very low level of interference in other parts of the metropolitan area. The configuration of a cellular radiotelephone system is a function of the local geography, the number of mobile transmitters in the coverage area (density), and the predicted amount of use. In very dense urban areas the size of each cell must be small (under one mile) to accommodate the heavy volume of communications, while in less dense areas the size of each cell can be much larger. Depending on the number and the length of calls, a single cell is capable of supporting up to 1200 subscribers on 40 channels.

Cells are linked to the mobile-telephone switching office (MTSO), commonly known as "the switch," by telephone lines or microwave. The MTSO controls the operation of each cell and is the primary point for interconnection with the

local telephone company. A simple cellular telephone system is illustrated in Figure 12.

Cellular telephones are microprocessor controlled and frequency synthesized. Eight hundred thirty-two full-duplex channels (less control frequencies) are allocated to the cellular radio service in the 800 MHz band. Channels are spaced 30 KHz apart, and transmissions are frequency modulated (FM). Each cellular telephone is assigned a unique electronic serial number by the manufacturer. This enables the system to identify and track each phone. Cellular phones are controlled by the MTSO over dedicated data channels. Computer equipment at the MTSO keeps track of which cellular telephones are logged onto the system. When a cellular user wants to make a call, or when the MTSO receives an incoming call from the conventional telephone network, the MTSO computer selects a vacant frequency pair and assigns it, via the data channel, to the cellular phone. The frequency synthesizer within the cellular phone is then programmed to operate on the assigned channels. Each of the cells receiving the phone's data signal is constantly monitored by the MTSO computer. As the cellular phone moves about, the strength of the received signal will change. The MTSO maintains the quality of the radio link by keeping the phone connected to the cell with the strongest signal. When phones move between cells, the "handoff" happens so fast that it is not noticed by the user. When the cellular phone moves outside the range of the system and the signal

Cellular Telephone System

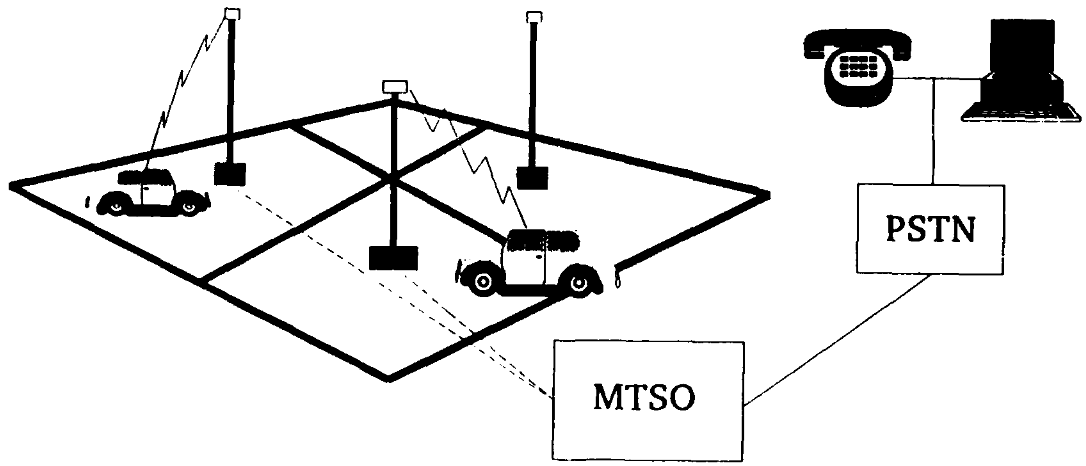

Figure 12. Cellular Telephone System

strength falls below a certain value, the phone will be disconnected. [Ref. 18:p. b]

Cellular is optimized for voice service, but data and facsimile (fax) can be transmitted with special modems. Cellular in its present configuration is inefficient for handling short data messages. For instance, a 100 character message at 2400 baud takes approximately one-third of a second to transmit, but the call setup and take down time is on the order of eight or more seconds. Even though the message was transmitted in less than a second, depending on the rate schedule, the mobile unit would generally be billed for a minimum of either 30 seconds or one minute. However, a few carriers offer a low cost, under-30 second dispatch rate. Despite these limitations, certain users find cellular to be an economic way to convey data.

The FCC has licensed two cellular carriers to operate in each of the 306 Standard Metropolitan Statistical Areas (SMSA's), and is in the process of awarding licenses in the 428 Rural Service Areas (RSA's).[13] The frequencies allocated to cellular telephone are divided into "A" and "B" blocks. The "A" block frequencies are assigned to "non-wireline" carriers and the "B" block frequencies are reserved for "wireline" carriers. The "wireline" carrier is usually

[13]Telephone conversation between Ms. Claudia Borthwick, FCC Cellular Telephone, and the author, 29 August 1989.

affiliated with the local telephone company. The "non-wireline" carrier is the company offering competitive cellular service in the same area. [Ref. 18:p. c]

Approximate cellular coverage as of April 1989 is shown in Figure 13. The dark lines are the interstate highway network. [Ref. 19]

3. System Networking

Common operating standards enable all cellular radiotelephones within the U.S. and Canada to be compatible with any cellular system in these two countries. This makes it possible for cellular telephone users to move from system to system, known as "roaming." Cellular system switches from different manufacturers are not compatible. However, since each cellular MTSO is connected to the public-switched telephone network (PSTN), it is possible for cellular telephone systems to be interconnected. This is illustrated in Figure 14.

Several methods have been worked out to allow roamers to freely access other cellular systems. The simplest method requires the user to contact the cellular system operator when first entering the coverage area. In some cases, this can be done with the cellular phone, in other cases a pay telephone must be used. The user generally provides the operator with a credit card number, his cellular telephone number, and the phone's electronic serial number (ESN). The caller is then authorized to use the system, generally paying a usage charge

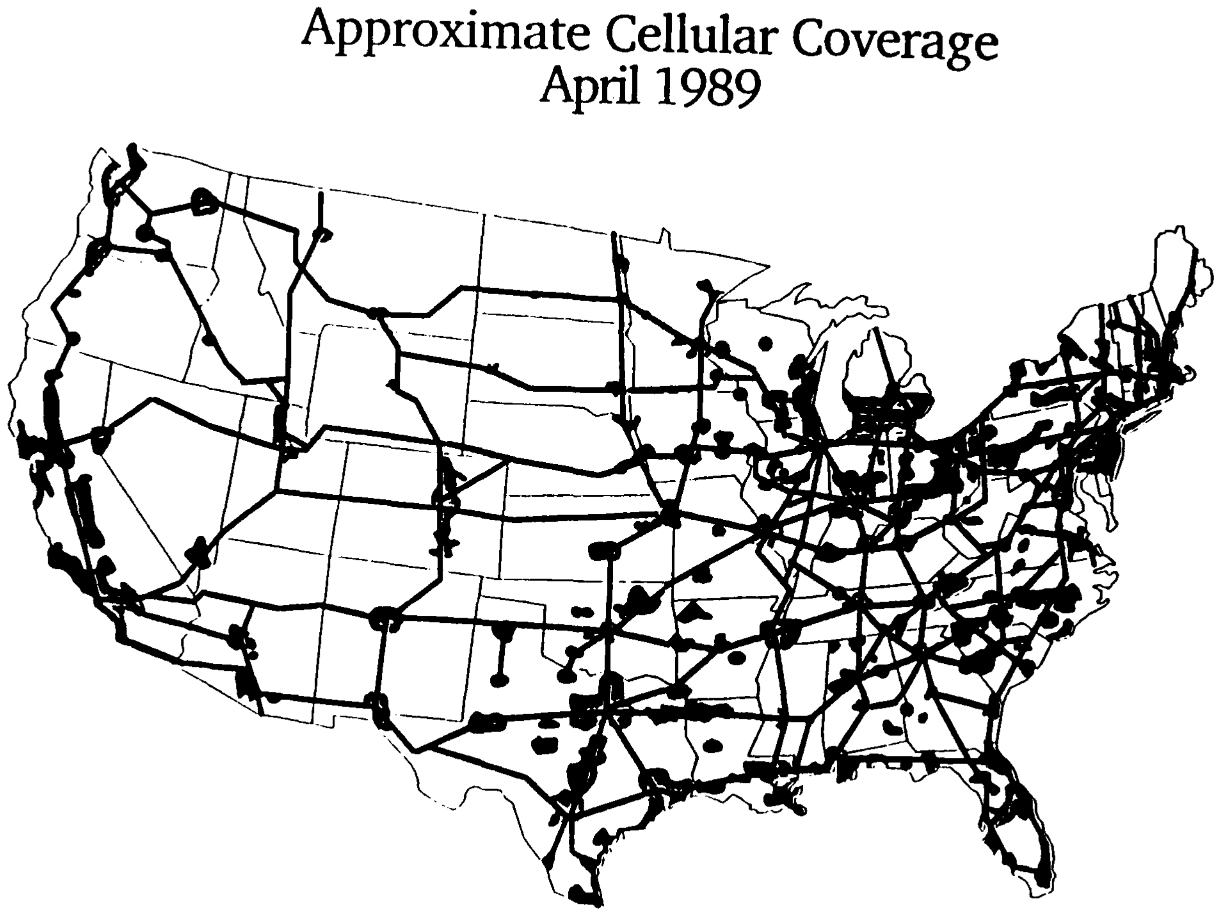

Figure 13. Approximate Cellular Coverage April 1989

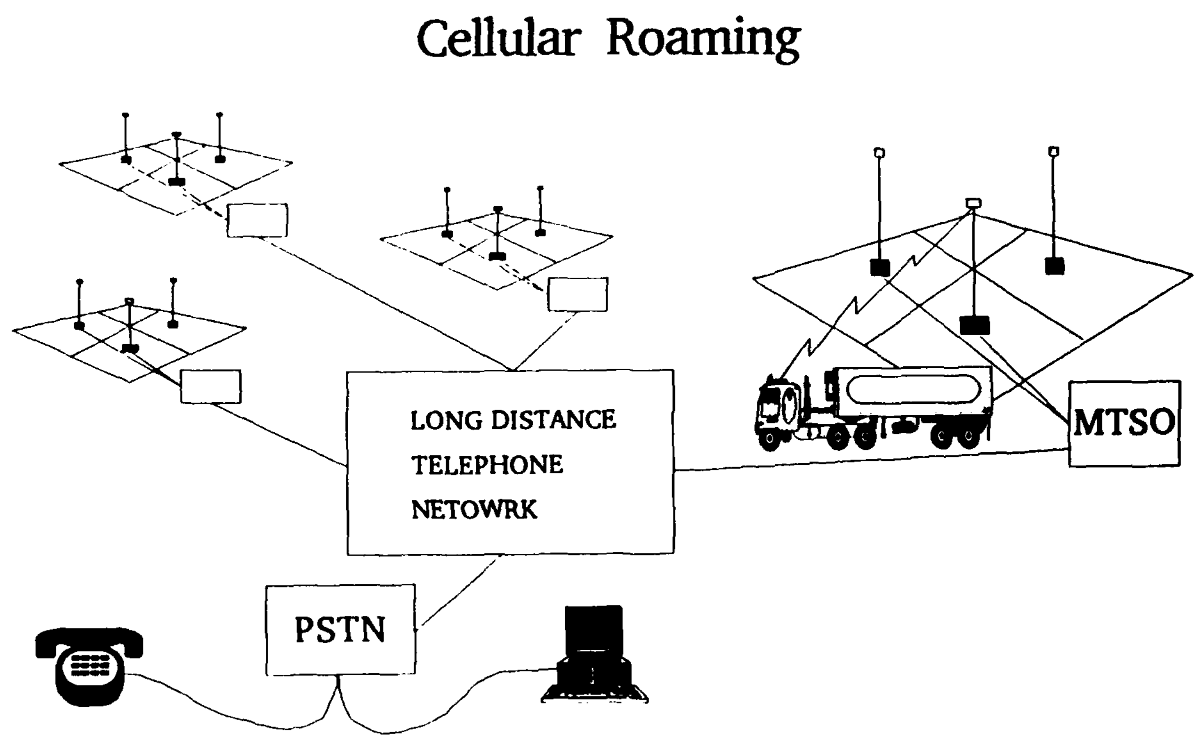

Figure 14. Cellular Roaming

of $2.00 per day plus $0.45 to $0.75 a minute for local calls. Long distance calls are billed at the appropriate rate plus local air-time charges. Once logged into a system the user can receive incoming phone calls as well.

To make the roaming authorization procedure easier, a system of reciprocal roaming agreements between cellular service providers has been established. On the first roaming call, the MTSO will analyze the ESN and the coding automatically transmitted by the phone to determine if the user comes from a carrier that has established a reciprocal service agreement with the host company. If the coding is not recognized, the caller will probably get a recorded message providing a customer service number. If a roaming agreement is in effect, the call will be put through. Charges for roaming under a reciprocal agreement will show up on the user's home carrier bill.

To contact a roaming unit, the caller dials the cellular system's roaming access number, waits for a second dial tone or series of beeps, then dials the roamer's ten digit telephone number. The MTSO accepts this number and sends a signal throughout all cells to contact the roamer. The disadvantage of this arrangement is the caller needs to know both the roamer's location and the system the roamer is operating on (wireline or non-wireline). With over 500 currently operating systems in the U.S. and Canada, this can be a problem. Most callers either wait until a prearranged

time, when the roamer is expected to be in a specific area, or wait for the roamer to check in. [Ref. 18:p. c]

To help resolve this difficulty, a service known as "Follow-Me Roaming" has been implemented in over 140 cities. This service lets callers dial the roamer's home area cellular number, and automatically transfers the call to the cellular system that the roamer is operating in. The long-distance transfer call is billed to the roamer by the long-distance carrier. Upon entering a system which has a Follow-Me Roaming agreement, the mobile user presses *18 SEND on the cellular phone, waits to hear a few confirmation beeps, and presses END. The user receives an automatic confirmation call following a successful log on.

4. System and User Costs

Based on a 1987 industry survey, cellular-system equipment cost between $600,000 to $1,000,000 per cell. This includes the costs of the radio and computer equipment, zoning hearings, cell site locations, microwave transmission facilities, equipment sheds and assembly costs. Amortized over five years, this is equivalent to $120,000 to $200,000 per year. Operating expenses raise these amounts further. [Ref. 17:p. 73]

Each time the cellular market doubles, the incremental production costs for cellular telephones has fallen by about 20%. This decline is illustrated in Figure 15. Radiotelephones that cost around $3000 when cellular technology was

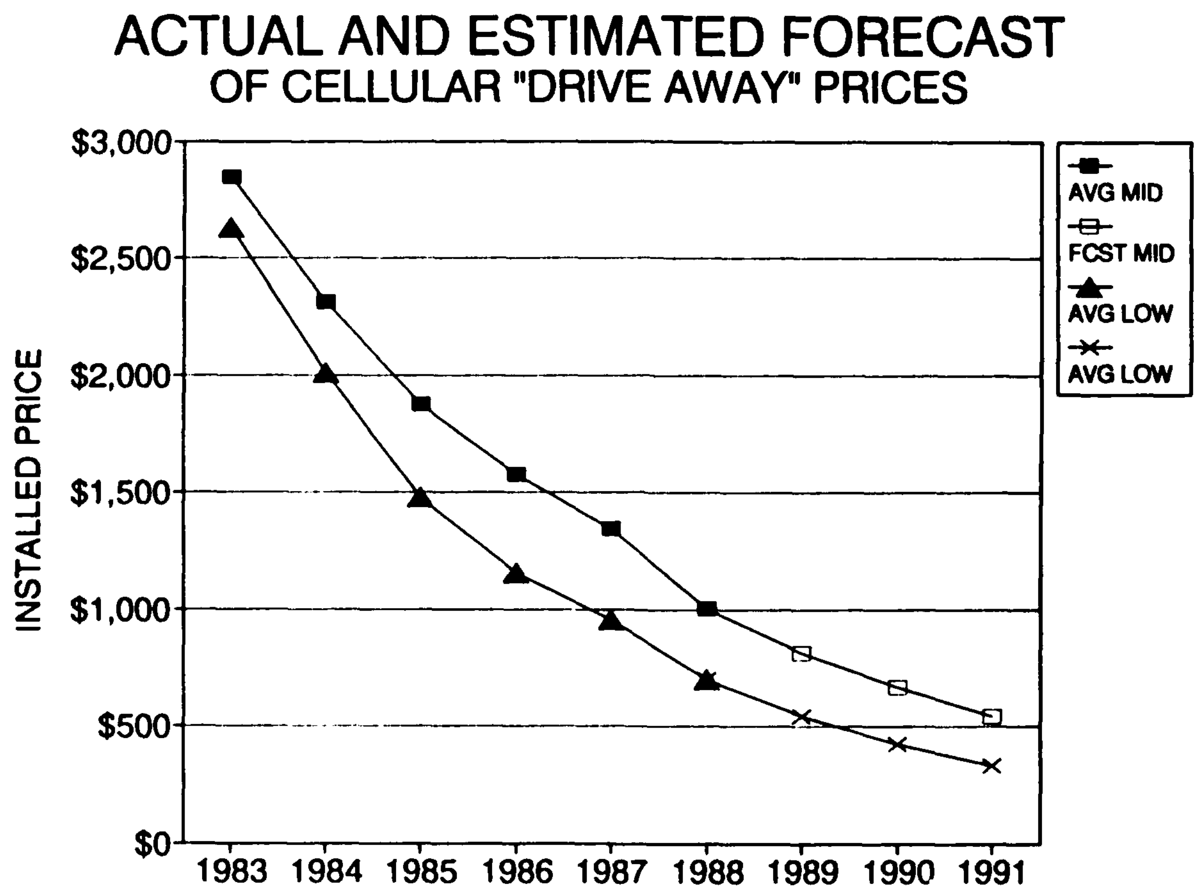

Figure 15. Actual and Estimated Forecast of Cellular "Drive Away" Prices

first implemented dropped to around $700 in 1988. The average "drive away" price for a mobile cellular telephone is estimated to fall to around $545 by the end of 1989 [Ref. 20:p 36]. However, low cost imports can be occasionally bought on sale for around $300 to $400 [Ref. 21]. The price of user equipment depends on the quality of construction and other features, such as data and fax capability. Monthly access fees for individual users and business range from approximately $7.50 to $20 per month in the smaller systems. Fees are as high as $50 per month in the larger systems and in areas where demand is heavy. Usage charges run from $0.20 to $0.90 per minute, again depending on demand for service, the time of day, and the cellular system. Discounts are given in some areas for multiple phones and volume calling [Ref. 18]. Figure 16 illustrates the rates in the top ten cellular markets [Ref. 22:p. 35].

5. Trucking Industry Cellular Services

One firm, Hellyer Communications (owned by Cummins Engine Co.), specializes in providing networked cellular service to the trucking industry. Hellyer provides a value-added service by maintaining roaming agreements with all wireline cellular systems in the U.S. and Canada, and presents trucking firms with consolidated, detailed billings. Various options are also provided the customer, such as programming the cellular phone to only make calls to certain numbers. These services make paying communication bills easier and help

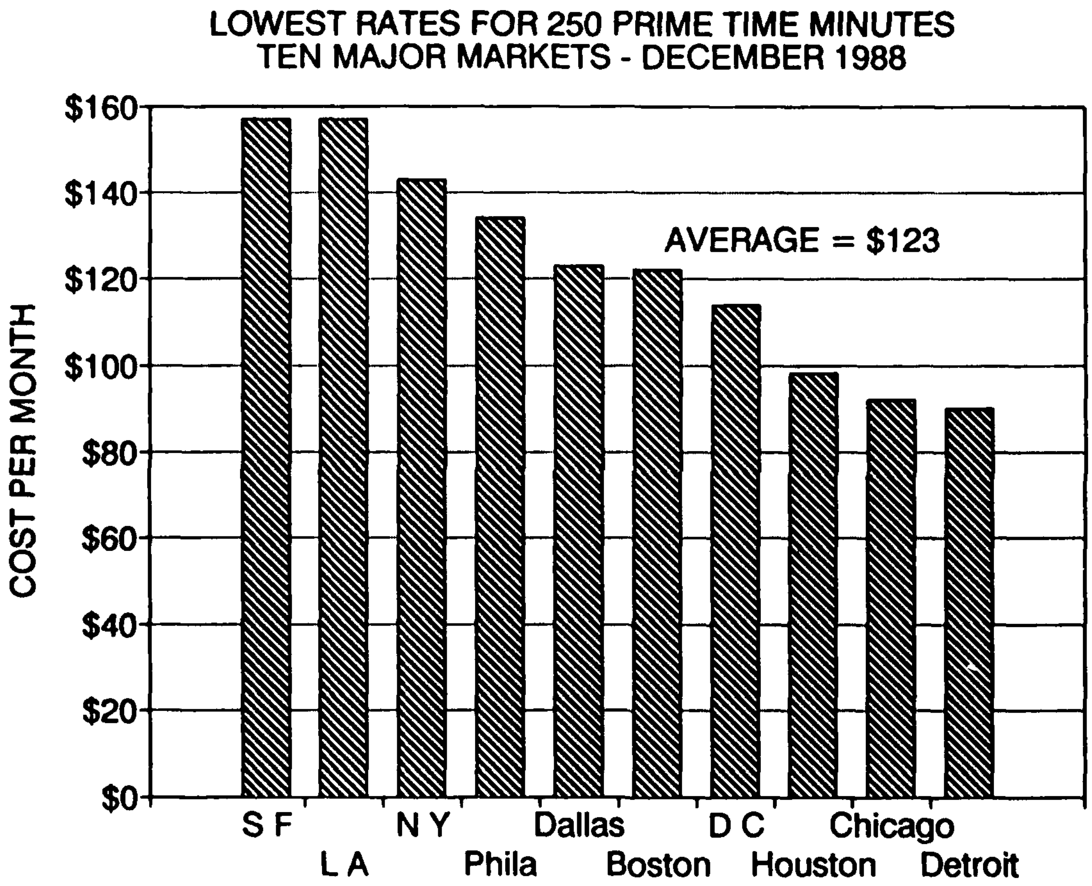

Figure 16. Lowest Rates for 250 Prime Time Minutes
Ten Major Markets--December 1988

control communication costs. Hellyer's monthly access fee is $22.00 per cellular telephone, with a one-time activation charge of $30.00. Follow-me roaming service is available for an additional $4.95 per month. Charges for cellular communications are variable with the service area, and are detailed in a book provided to each Hellyer customer.

Hellyer uses the Cummins Truckphone, which is manufactured by Novatel. The phone sells for $800 (including installation) and is optimized for trucking industry use. Among other features, the Cummins phone is ruggedized, has a hands-free microphone, a horn-alert function to let the driver know he is receiving a call when the ignition is turned off, and a five-year warranty. The Cummins Truckphone is marketed, installed, and serviced throughout the U.S and Canada by Cummins distributors and branches. Hellyer also markets several cellular fax and data terminals. [Ref. 23]

6. Cellular Industry Issues

a. Demand For Service

Figure 17 is an approximation of the general business demand function for cellular telephone in 1982 and forecast for 1989 and 1995. These demand curves were developed by Dr. Herschel Shosteck, a cellular industry economist. Expressed in constant 1982 dollars, the functions illustrate the approximate elasticity of demand for mobile telephone service and the forecast increase in demand [Ref. 24]. Elasticity of demand refers to the percentage change of

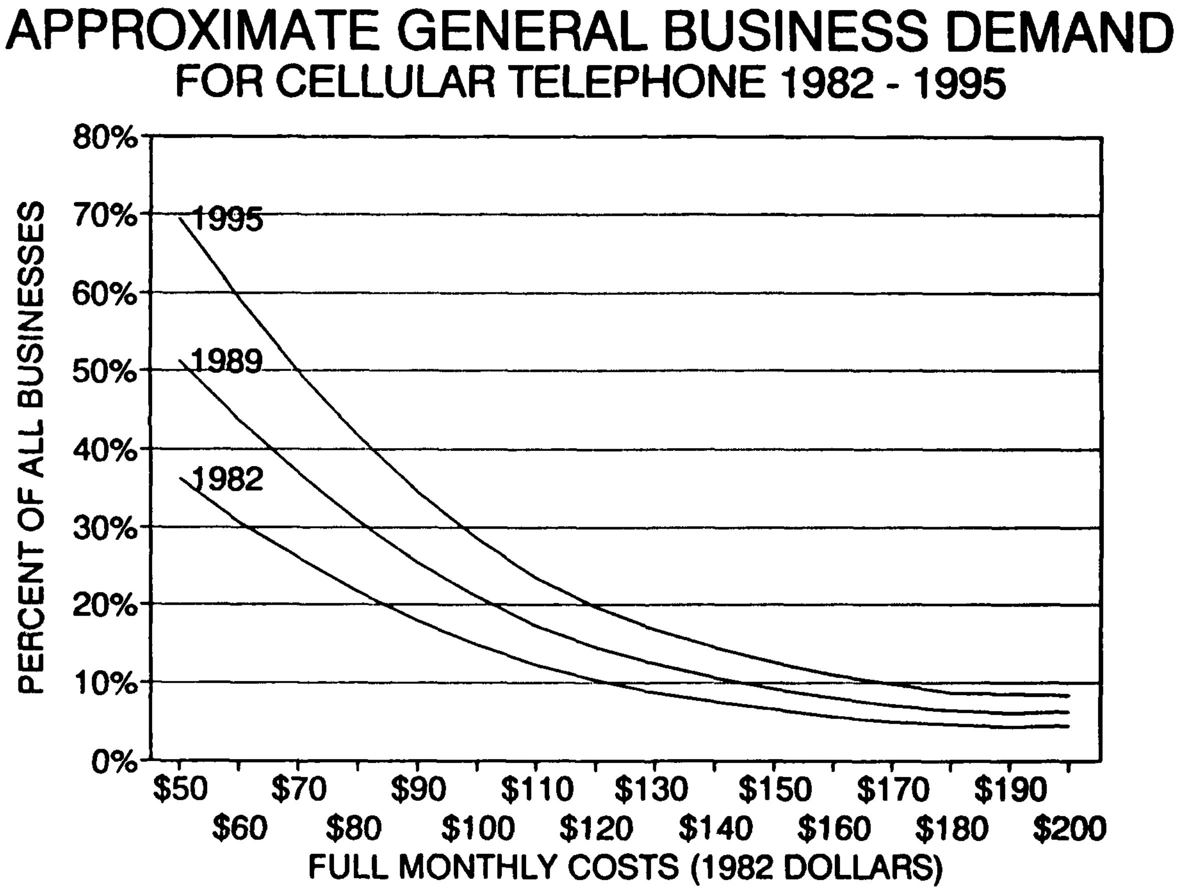

Figure 17. Approximate General Business Demand for Cellular Telephone 1982-1985

quantity demanded resulting from a percentage change in price. Increase in demand refers to growth in the purchase of a good without a decline in price [Ref. 25:pp. 20-26].

These curves have increasing slopes as the fully-distributed monthly costs (amortized cost of the cellular phone at three percent per month, service and usage charges for 250 minutes per month) decrease. The curves illustrate that quantity demanded grows slowly until fully allocated costs are between $125 and $100 in constant 1982 dollars. As user costs approach $100 a month, a given percentage reduction in price spurs a correspondingly greater percentage of demand. The upward shifts in the demand functions are attributed to "educating the market," improved telephone functions (such as hands free operation) and new, alternative uses for cellular telephone. [Ref. 17:pp. 72-73]

b. Cellular System Costs

With an average capital cost of between $600,000 and $1,000,000 per cell, the incremental costs of expanding capacity are substantial. In an urban area where up to 1200 subscribers could support each cell, the minimum incremental capital cost per subscriber ranges from $500 to $833. The subscriber's share of the MTSO and fixed operating costs over the life of the equipment raises this amount. PacTel Cellular

estimates the fully distributed cost per customer is approximately $1200 for its Los Angeles system.[14]

Because of these incremental expansion costs, cellular radio in its current form does not offer much economy of scale. The reason for this centers on the limitation of current analog FM technology and the number of allocated channels. Once cell capacity is reached, the cellular system operator must add additional cells. However, adding these new cells is very costly and consumes a large portion of the additional generated revenue. In addition to these financial limitations, the cellular division process can not continue indefinitely because of physical radio frequency (rf) constraints. Eventually a point will be reached where the further subdivision of cells is impossible without creating interference and other service quality problems. Cellular systems nearing capacity limits are located in Los Angeles, Chicago, and New York City.

With the exception of LIN Broadcasting Corp., cellular companies have yet to turn a profit. Most earnings have been used to expand cellular systems. The spectacular rise in cellular stock prices during 1988 and 1989 is due primarily to expectations of further growth and eventual bottom-line profitability. [Ref. 21]

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[14] Spread-spectrum (CDMA) cellular telephone presentation made by Qualcomm, Inc., San Diego, Ca., 13 November 1989.

c. Digital Modulation

Since additional channels are not available, the cellular industry is working on the development of digital equipment to expand system capacity. Analog FM, which permits only one voice conversation per channel, will eventually be superceded by either time division multiple access (TDMA) or code division (spread spectrum) multiple access (CDMA). TDMA enables at least four simultaneous conversations to carried over each channel, while CDMA expands channel capacity by a factor of up to 20. The similarity of TDMA and CDMA systems ends with the requirement to use digitized voice. Prototypes of both systems have been successfully demonstrated. The mechanics of these modulation systems are discussed in more detail in Appendix B.

(1) Cellular TDMA. TDMA cellular phones operate over conventional analog channel spacing and bandwidth. All TDMA cellular phones are part of a synchronized communications network. When in use, a specific channel and time interval is assigned to each phone by the MTSO. The voice signal is digitized and divided into packets of data which are compressed in duration and transmitted at precisely-timed intervals. The duration of these compressed data packets is so short that data packets from three other conversations can be inserted sequentially into a timing frame. To recover the information, the receiver extracts the proper data packet from within the transmission frame and decodes it. The expansion

of the data packets fills the "gaps" created by the compression, and the transmitted speech is reconstructed without noticeable distortion.

Although TDMA provides an increase in total subscriber capacity, it does not overcome the other limitations of conventional analog cellular telephone. Designers must still deal with the interference problem caused by frequency reuse in other cells. With conventional FM analog and TDMA cellular systems, "worst case" interference scenarios still govern the portion of time in which the desired signal quality levels will not be achieved or when calls will be blocked.

(2) Cellular CDMA. Unlike conventional analog FM and TDMA systems which operate on 30 KHz wide channels, CDMA cellular telephones operate over 1.25 MHz wide band segments. CDMA achieves signal separation by the use of different binary codes to modulate each carrier and spread out the waveform. This allows CDMA signals to be overlaid on top of each other in both frequency and time. A correlator circuit in the receiver uses the same binary code for despreading the signal and recovering the intelligence. All the other signals, each of which use a different binary spreading code, resemble background noise and are filtered out.

Spread spectrum signal-to-noise ratio and frequency reuse efficiency are determined by the number and strength of all other transmissions within range. The

signal-to-noise ratio is improved by the ratio of the spread spectrum bandwidth to the data rate. This is known as processing gain and allows spread-spectrum cellular telephone systems to operate at lower signal strengths than analog FM or TDMA. As long as the strength of a desired signal is above a certain background threshold value, there will be an acceptable level of communications quality.

Since CDMA is purposely designed to operate with interference from other signals, the total capacity of a properly designed spread-spectrum cellular system is larger than conventional analog FM or TDMA configurations. Cellular CDMA system performance is statistically governed by the number and concentration of users simultaneously transmitting over the same 1.25 Mhz bandwidth. CDMA system design and service quality is based on the expected <u>average</u> amount of use. Heavier than expected system use causes a reduction in the signal-to-noise ratio. This produces an increase in the digital bit error rate experienced by all users and causes a gradual decline in service quality as the number of users increases. This contrasts with conventional analog FM and CDMA cellular systems, where interference from other transmitters on the same <u>channel</u> governs system performance. The degradation of service quality is much more pronounced in these systems, and they must be configured taking <u>worst case</u> situations into account. Whereas a heavily-loaded cellular CDMA system may suffer an acceptable degradation in signal

quality, analog FM and TDMA under equivalent loading conditions can experience unacceptable interference or blocked calls.

The CDMA system also has other advantages. The hand-off process between cells is less complicated because the phone does not have to change frequency. The mobile continues to transmit using the same binary spreading sequence, and the new cell switches and synchronizes a demodulator to this code. The ability to use lower power transmitters in a CDMA cellular system will decrease the cost of mobile units and permit portable units to use smaller and lighter battery packs. Mobile-transmitter power control is also used to ensure adequate signal levels are maintained. This system measures received power at both the mobile and cell site, and commands the transmitter to make the appropriate adjustments. This helps conserve battery power, minimizes interference to other units, and reduces the effects of fading.

The CDMA system incorporates voice activity detection. Each person talks about 35% of the time in a typical two-way voice conversation. Analog FM and TDMA systems require cell site and mobile transmitters to remain on during pauses between speaking. With CDMA, it is possible to turn the transmitter off when there is no speech. This conserves portable battery power and reduces the average

background noise level experienced by other CDMA cellular units.

CDMA permits variable voice and non-voice data rates to be used without changing the appearance of the spread spectrum signal. Slower data rates require less power to transmit since a lower signal-to-noise ratio is allowable. Low data rate transmissions at reduced power levels diminish the background noise of the entire system and increase total communications capacity. This flexibility allows various grades of voice and data services to be offered. Service providers can link per-minute charges with data rates to encourage users to maximize total system capacity.

The structure of the CDMA signal provides additional advantages. Unless a receiver is set to and exactly synchronized with the transmitter's binary spreading code, it will be impossible to despread the signal and recover the intelligence. The population of approximately four billion CDMA cellular codes provides a high degree of communications security. Multipath effects are also minimized. Signal propagation delays greater than a certain value will not correlate, and appear to the receiver as additional background noise. This eliminates the additional multipath-filtering circuitry required for analog FM and TDMA systems. Finally, using three or more cell sites to measure the difference in the time of arrival of CDMA signals allows position determination with car-length accuracy. This could

permit location coordinates to be displayed on the cellular phone and at remote sites, such as a dispatcher's console.[15]

(3) Implementation. The Cellular Telephone Industry Association (CTIA) is reviewing both TDMA and CDMA systems. The TDMA specifications are planned to be finalized by the Summer of 1990.[16] PacTel Cellular plans to implement Qualcomm's cellular CDMA system in the Los Angeles area beginning in the fourth quarter of 1990, and is encouraging other cellular operators and manufacturers to follow suit. PacTel will obtain a capacity increase of more than 300% by converting only 10% of their analog channels to CDMA.[17]

When digital cellular equipment becomes commercially available, capacity increases will not automatically require additional outlays for new cell sites. Conversion to digital will require reconfiguring some of the hardware and software at each cell site and changing the software at the MTSO. The incremental costs per subscriber for digital conversion of existing cells will not include the costs of zoning hearings, cell sites, towers, structures and equipment common to both analog and digital systems.

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[15]Spread-spectrum (CDMA) cellular telephone presentation made by Qualcomm, Inc., San Diego, Ca., 13 November 1989.

[16]Telephone conversation between Mr. Kelly, CTIA, and the author, 18 August 1989.

[17]Presentation made by Mr. Craig Farrill, Vice President PacTel Cellular, at the Qualcomm cellular CDMA demonstration, San Diego, Ca., 13 November 1989.

Amortized over a four (TDMA) to 20-fold (CDMA) increase in capacity, the average capital and fixed operating expense per subscriber will drop. With increased capacity, cellular service providers can reduce their charges and be profitable. As discussed above, once fully-allocated user costs approach $100 per month in constant 1982 dollars, a further reduction in cost spurs a correspondingly greater increase in demand. With increased capacity and a rate structure that allows average user costs to fall within this region of the demand curve, cellular system operators should enjoy increased total revenues and profits. In situations where demand for increased capacity is less price sensitive, as in perhaps some major metropolitan areas, the service costs can remain fairly constant and total supplier revenues will also increase. In either case, the public benefits from increased service capacity and the competition between service providers exerts a downward pressure on rates.

With a multi-billion dollar investment in analog cellular systems and cellular radiotelephones, analog and digital equipment will function side-by-side for five to ten years. A major problem faced by the cellular industry will be the cost of the first generation of digital cellular phones. Because present analog equipment is relatively low in cost, users will have to be provided some sort of incentive or subsidy to by an initially higher cost digital phone. This may come in the form of a 20% to 30% decrease in rates.

Equipment price subsidies may also be offered by system operators. Roamers will probably have to buy a dual analog-digital phone to ensure compatibility with each type of system. In the long run, dual capacity phones should not cost much more than their analog predecessors because of eventual high production volumes and the use of very large-scale integrated circuits (VLSI). [Ref. 17:pp. 74-75]

Digital modulation will eliminate the additional specialized modem circuitry and communication protocols required for analog fax and data communications. The CDMA soft-handoff procedure, where a connection with the new cell is made before communications with the previous cell is broken ("make before break"), will enable data communication to be simpler and more reliable than under the present analog "break before make" system. This will reduce the cost of mobile FAX and data terminals which presently range between $1000 and $2500.

d. RSA Expansion and Coverage

In a multi-cell cell analog RSA where demand was a third that of a dense urban area (400 subscribers), the capital cost per subscriber would range between $1500 and $2500. Generally speaking, the population in rural and semi-rural areas tends to be less affluent. Other voice communication options, such as CB radio, SMR, and conventional mobile telephone also exist. In less dense areas these services are not necessarily subject to the frequency congestion and

capacity limitations which led to the development of cellular telephone. Cellular telephone will probably have to provide better voice service, be more cost effective, or provide added services in order to dislodge large numbers of established users from other voice systems. The 800 MHz cellular frequencies generally do not propagate as far as some of the alternative lower-frequency systems, and hence provide less geographic coverage for the same transmitter power and antenna configuration.

Based on these limitations and the cash flow required to pay off system investment and operating expenses, the expansion of multi-cell systems into all RSA's may be limited in the near term [Ref. 26]. The degree of cellular radiotelephone coverage within each RSA will also depend on population density and subscriber revenue limitations. The recent development of inexpensive one-cell switches and billing equipment, costing around $190,000 ($250,000 with installation and antenna system), reduces the incremental cost per subscriber and enables cellular service to be provided in areas which could not support a conventional multi-cell system. For example, with an average revenue of $75.00 per month, 200 subscribers (one percent of a 20,000 population) will generate $180,000 a year in revenue. This is more than enough to cover the capital and administrative costs of the

system. These one cell systems in some respects resemble specialized mobile radio (SMR), which is discussed below.[18]

Since roaming users will raise the effective population density of a rural service area, operators will locate their systems to provide coverage of major highways. Figure 18 shows the relative coverage of the planned RSA expansion. The small circles are roughly centered on the largest town in each RSA. When implemented, the actual coverage will be different from these small circular areas.

e. Cellular Industry Growth

The above factors serve to expand both the capacity of existing cellular systems and increase future geographic coverage. Average costs per user should decline as well. Figures 19 through 21 illustrate the actual and forecast declines in the full effective cost of cellular service. In constant 1982 dollars, the price of owning a cellular phone and talking for 250 minutes per month fell from $240 in 1982 to $129 in 1987 [Ref. 22:pp. 17-22]. Dr. Shosteck forecasts the cost will decline to $100 in 1989, and fall to $50 in 1995 due to the incremental cost reductions from digital systems [Ref. 17:pp. 75-76].

Figure 22 shows the actual and forecast growth in the cellular subscriber base from 1983 through 1995. This graph takes into account business, government, consumer, and

[18]Telephone conversation between Mr. William Deford, Vice President of Sales, Plexis Corp., and the author, 7 June 1990.

Planned Rural Service Area Expansion

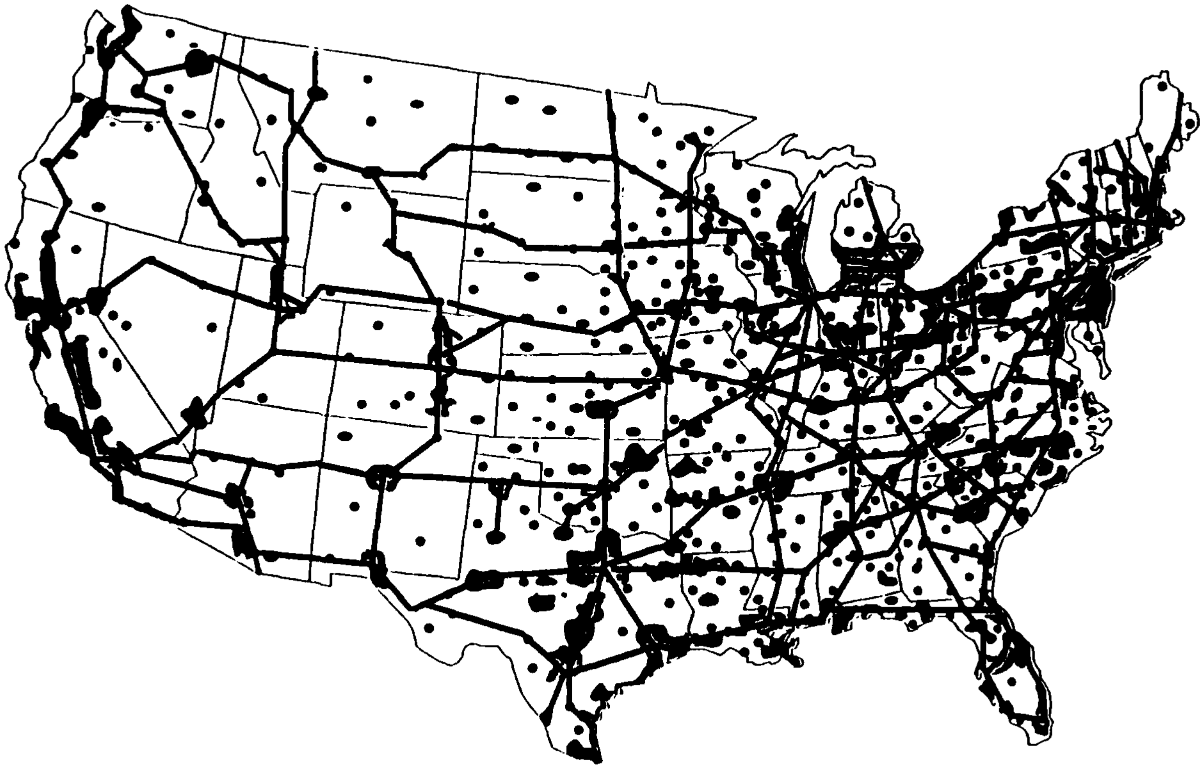

Figure 18. Planned Rural Service Area Expansion

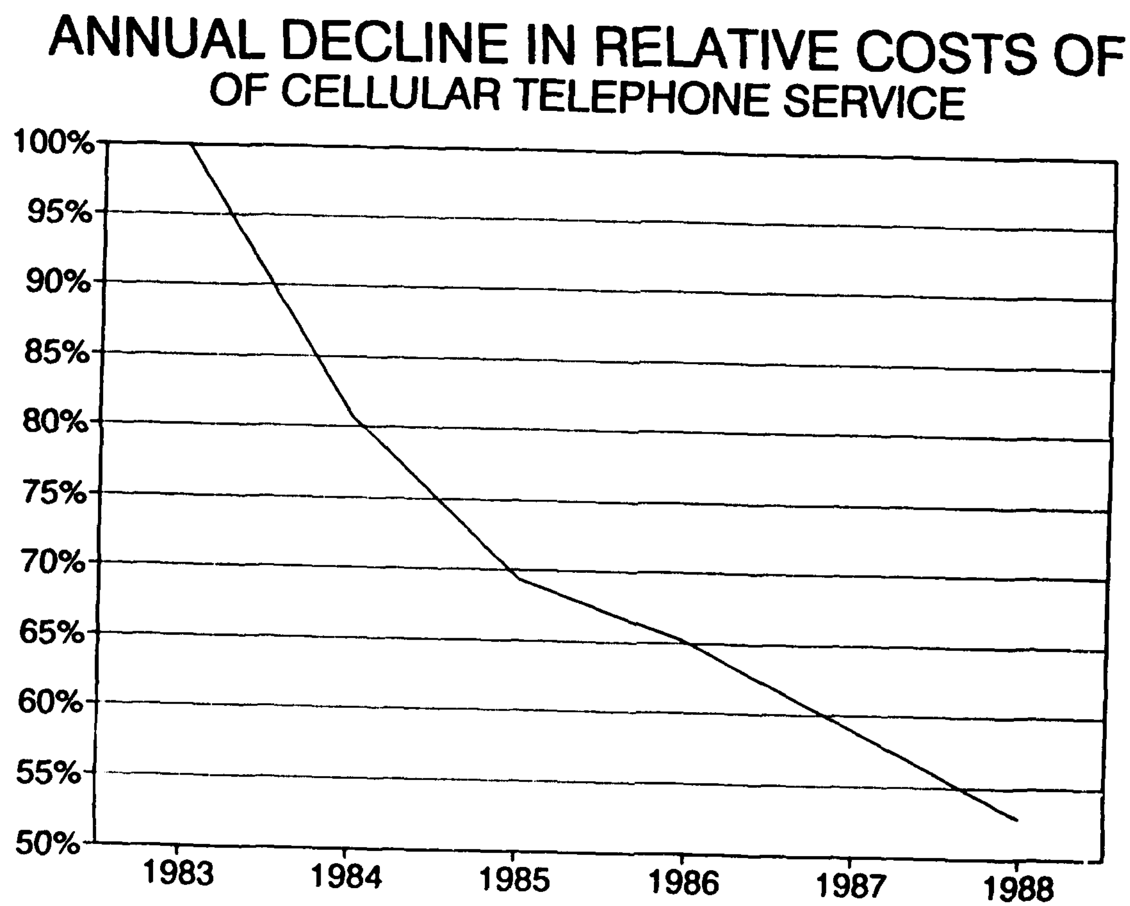

Figure 19. Annual Decline in Relative Costs of Cellular Telephone Service

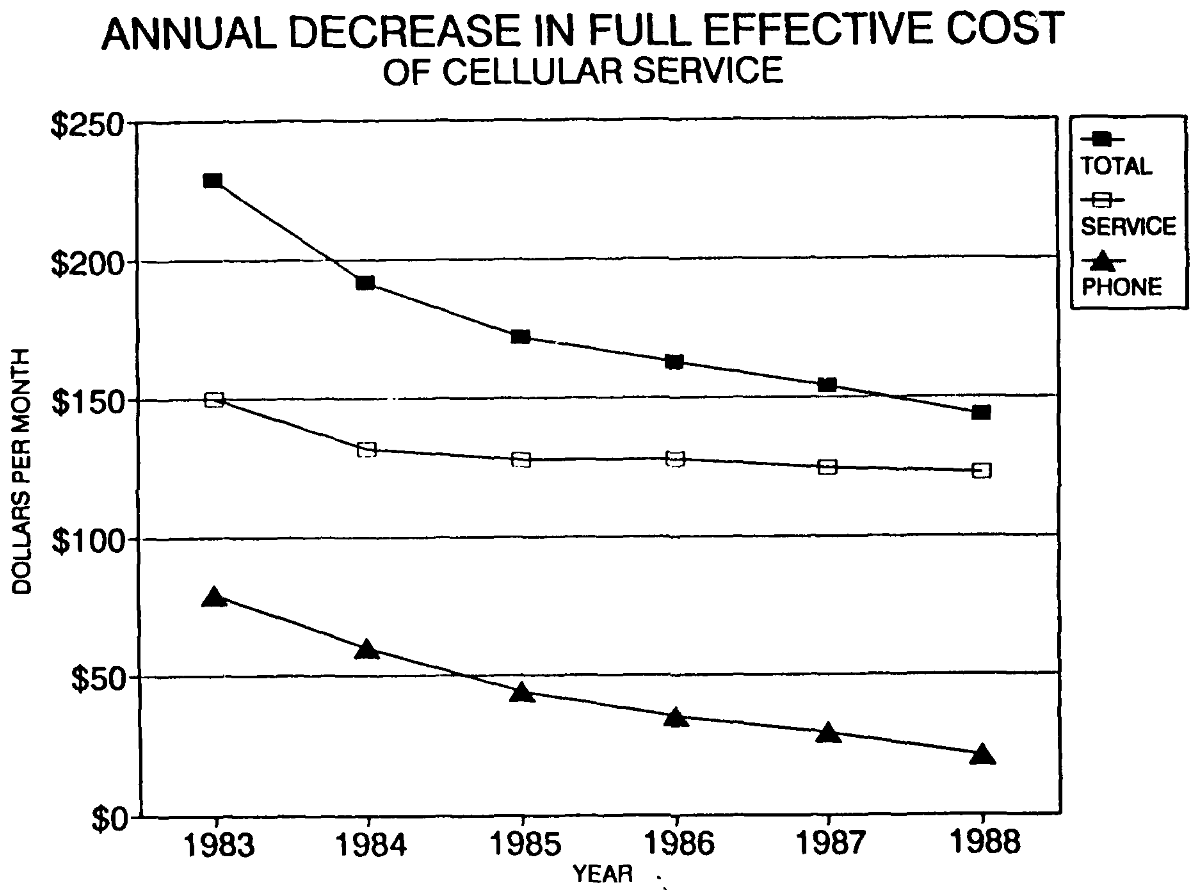

Figure 20. Annual Decrease in Full Effective Cost of Cellular Service

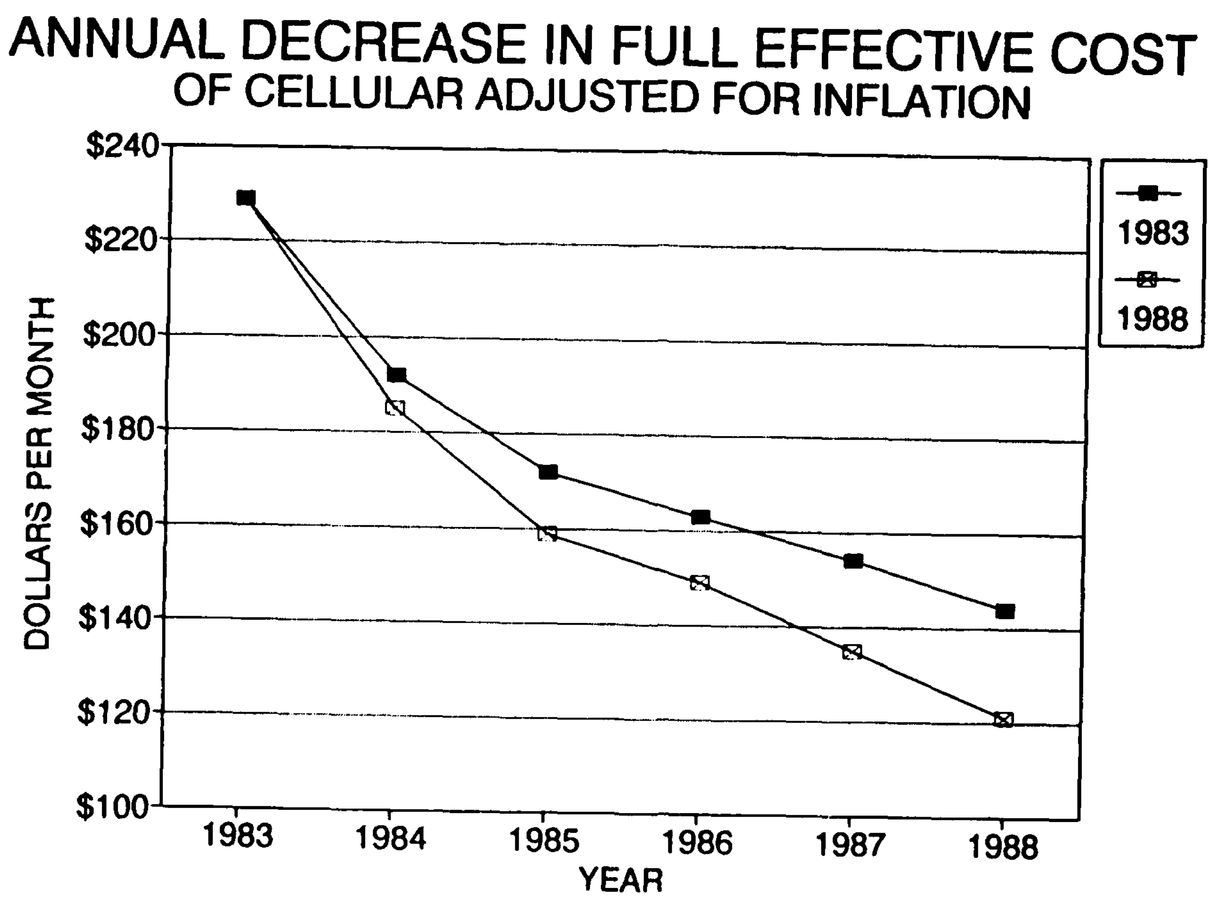

Figure 21. Annual Decrease in Full Effective Cost of Cellular Adjusted for Inflation

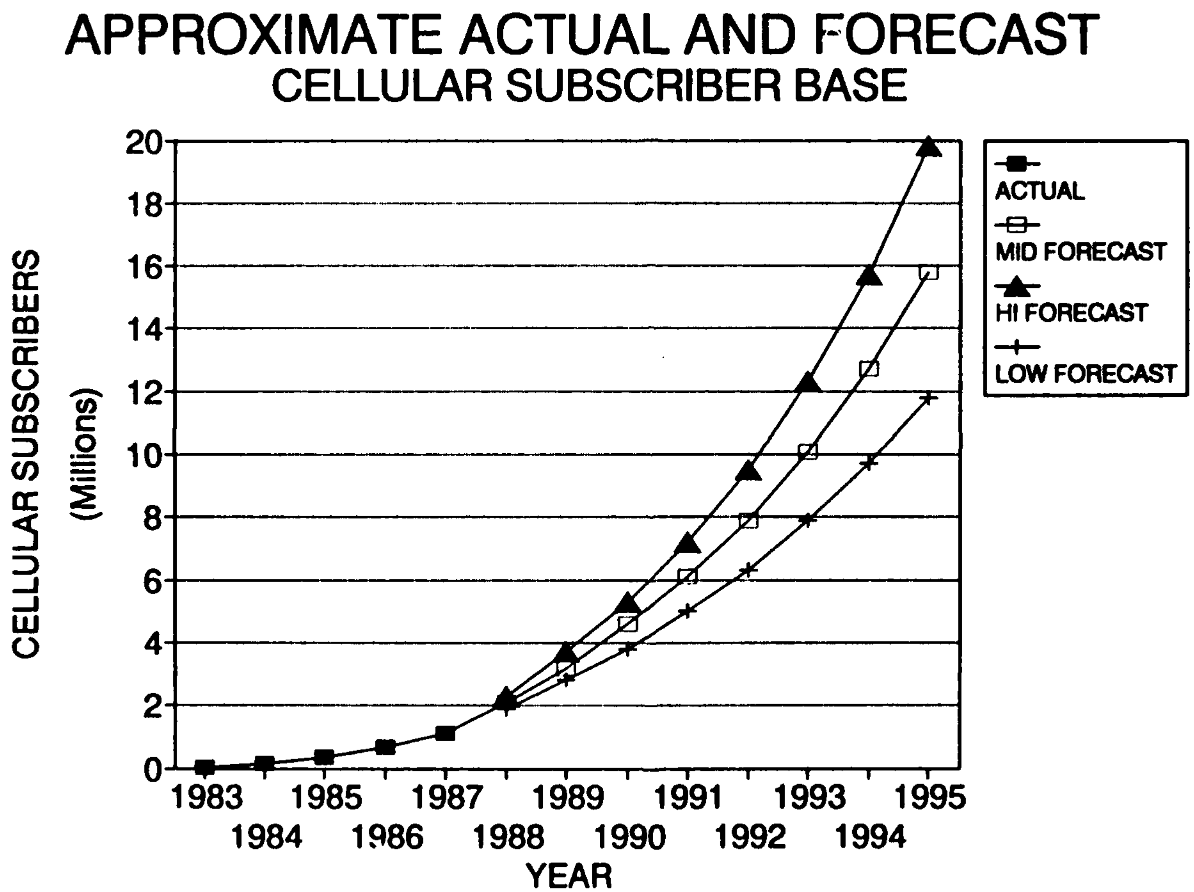

Figure 22. Approximate Actual and Forecast Cellular Subscriber Base

fleet dispatch use. The December 1995 mid-level forecast is 16 million subscribers, up from an estimated 3.4 million in 1989. [Ref. 22:p. 15]

7. Future Cellular Systems

With the eventual migration to a digital standard, capacity increases of up to 20 times, and service cost reductions, portable cellular phones may become a widely-used substitute for conventional land-line telephones. It will also be less expensive and more efficient to use cellular for data transmission. Modification of cellular systems may enable the widespread use of digital cellular for applications such as portable computer networking, messaging, fax, and dispatch operation in a manner similar to the mobile data systems described below. Local systems could be networked into a nationwide cellular mobile data system through a combination of very small apertaure terminals (VSAT), fiber optics, and land line. Vehicle tracking services may also be provided. Miniature, two-way nationwide alphanumeric cellular pagers could eliminate a drawback to existing paging services, where the sender does not know if the page was received.

Expansion into the RSA's will bring the majority of the U.S. population under the cellular umbrella, but large geographic areas will remain that are to thinly populated to support any type of terrestrial system. Mobile voice and data services in these areas will require the use of a satellite. Combined cellular and mobile satellite terminals will

eventually be developed for roamers who frequent areas without cellular coverage. [Ref. 27]

F. SPECIALIZED MOBILE RADIO

1. Background

Like cellular radiotelephone, specialized mobile radio (SMR) was developed in response to the demand for additional radio communications. SMR systems are intended for use by the same groups that use conventional two-way voice radio. In addition to voice-dispatch services, SMR can provide mobile telephone, mobile data, and paging services. There are over 600,000 SMR transceivers in operation.

The original 200-channel SMR allocation in the 800 MHz band was made by the FCC in 1976. An additional 400 channels in the 800 MHz band were later added because of demand. In the fall of 1987, 399 additional channels in the 900 MHz band were annexed. [Ref. 28]

Any person or organization, except for a telephone company, is eligible to apply for a SMR license. SMR systems are generally owned by an entrepreneur who sells the communication service provided by his equipment to a variety of SMR users. In areas where frequencies are available, all that is needed to apply for a license is a system plan on paper, completed application forms, and payment of a $30 processing fee. The FCC does not require an engineering study or financial commitments from prospective users. Frequencies

are assigned in blocks of five channels in the 800 MHz band and in blocks of 10 channels in the 900 MHz band. The FCC does not regulate the SMR operator's charges. The one exception to this rule is that a SMR operator may not resell at a profit the services or facilities of a common carrier, such as the telephone company.

In a waiting list area, where all available channels have been authorized for use, SMR systems must have a minimum of 70 mobiles per channel at the conclusion of the initial five-year license. An operator whose system is not used to this capacity will have the license renewed, but only at the rate of 100 mobile units per channel. There is no loading requirement for channel retention in areas where frequencies are still available. [Ref. 29]

The ease of obtaining a license to provide service, combined with the relatively low cost of system and user equipment, has led to a proliferation of SMR systems. In 1988, there were more than 2000 SMR systems in operation throughout the U.S. [Ref. 1:p. 29]. Mexico and Canada also have SMR service which is available to U.S. users by permit [Ref. 29].

2. SMR System Configuration

Figure 23 shows the configuration of a local area trunked SMR system [Ref. 1:p 27]. The typical user has a base station for communication with SMR equipped units. The SMR service provider has a repeater site consisting of antennas,

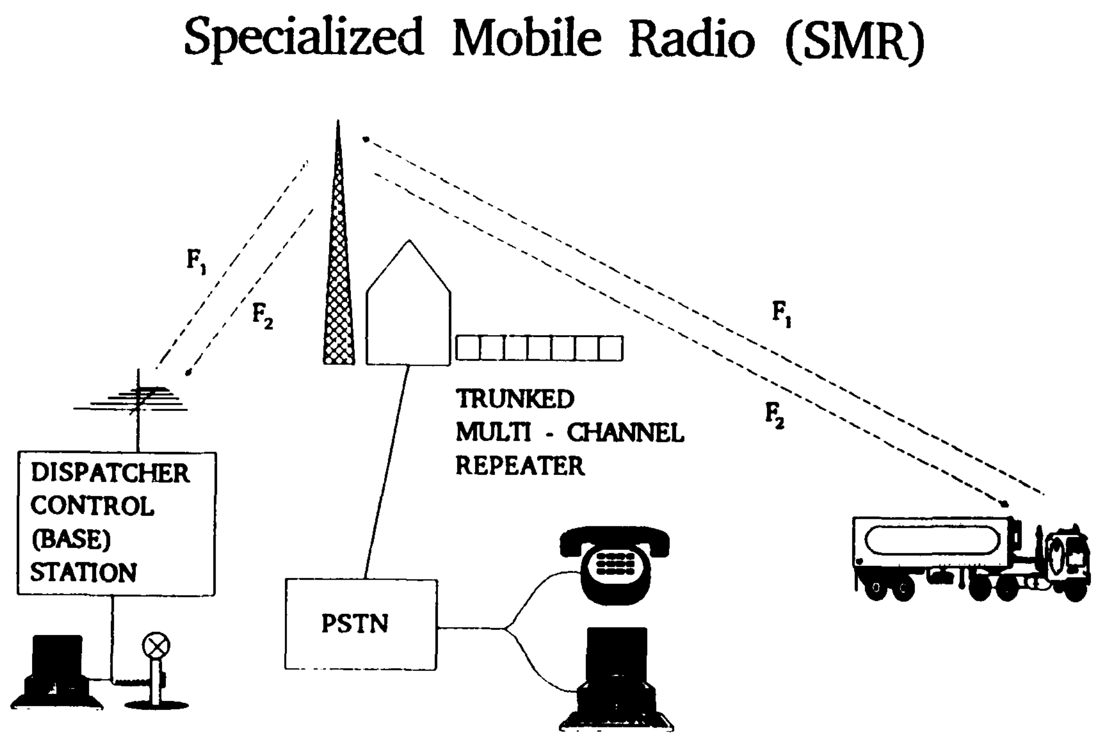

Figure 23. Specialized Mobile Radio (SMR)

computer and communications equipment, and physical plant. The SMR repeater can be tied into the local telephone system to permit mobile units to make and receive radiotelephone calls. User equipment is microprocessor-controlled and frequency-synthesized.

3. System Operation

a. Single Site

SMR base stations and mobile radios operate through repeaters, which are usually located above the surrounding terrain and transmit at a higher power level than user radios. This enables the radio coverage area to be maximized. Base stations and mobile radios transmit on one frequency, which the repeater receives and retransmits on another frequency.

SMR systems can be conventional or trunked. Conventional refers to systems that use single channels, and resemble community repeaters. The main drawback to shared single channel systems is they are frequently occupied and the next user must listen and wait until the channel is available.

Trunked SMR refers to systems which pool between five and 20 channels so all system users can access any channel that is not in use. The bank teller analogy shown in Figure 24 conceptually illustrates trunking. At the "conventional bank," customers are restricted to standing in specific lines. Some lines move faster than others, and customers who have to wait for longer periods are not happy

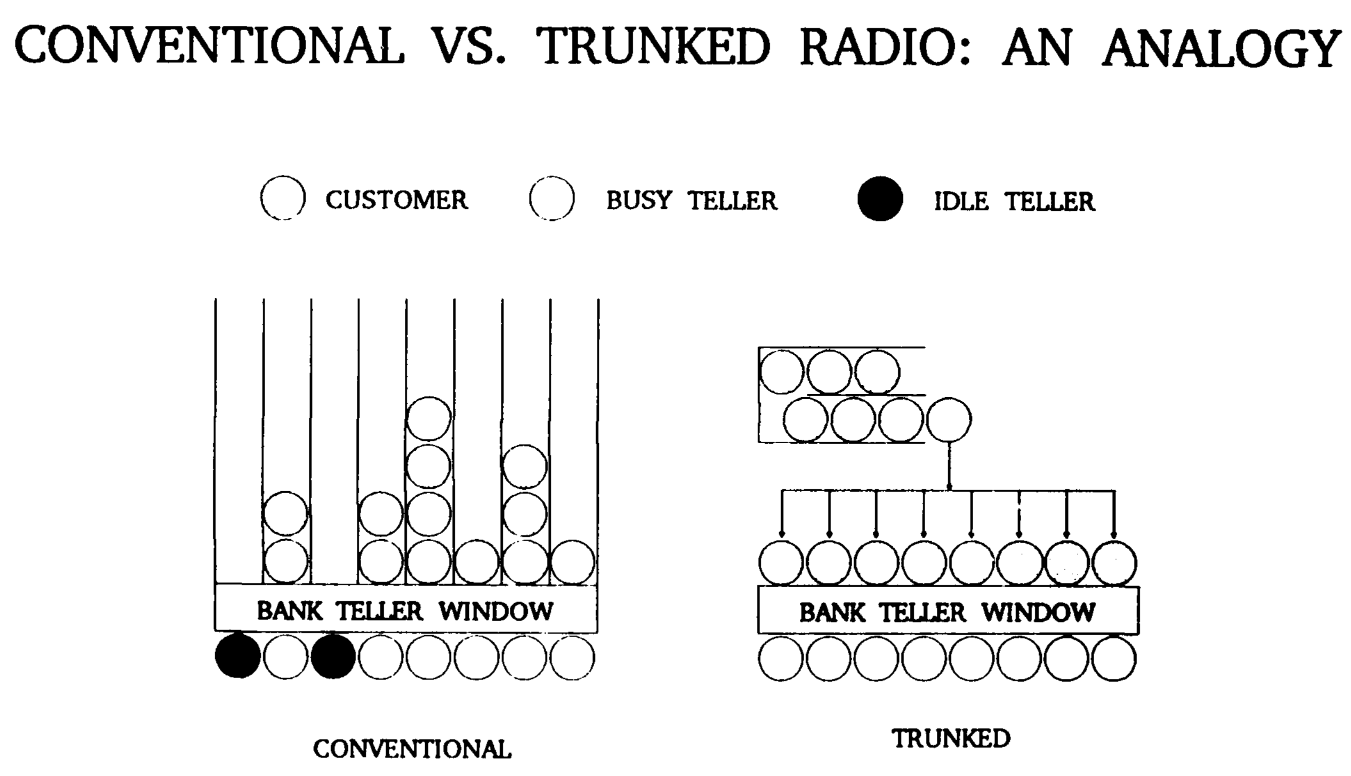

Figure 24. Conventional vs. Trunked Radio: An Analogy

with the level of service. Tellers without customers are inefficient and a waste of productive capacity. Over at the more efficient "trunked bank," all customers wait in one line and feed to the next available teller. This increases the overall level of customer service and productive use of the tellers. [Ref. 30]

The three major U.S. manufacturers of trunked SMR equipment each use a different logic and trunking format (all incompatible with each other), but the basic theory is the same. All SMR radios assigned to the system have a unique identification code which is assigned by the SMR system operator. These radios constantly monitor a data broadcast which contains information on which repeaters are free and also signals when the radio is being called. Two-way system logic assigns repeater channels when initiating or receiving a call. Trunking five to 20 SMR frequencies in this manner increases the communication capacity of each channel four to six times respectively. A 20-channel SMR system can serve up to 2500 users [Ref. 1:pp. 26-31].

The use of unique identification codes also enables selective calling of radios or groups of radios. Privacy is also permitted because the only time the radio's audio will be on is when in actual conversation with another unit.

b. Multiple Sites and Networks

SMR systems are capable of operating from multiple sites and can also be networked to expand the area of coverage. A SMR network is illustrated in Figure 25. Existing network operating systems have limited regional coverage and capabilities. Americon and Motorola are developing advanced regional and nationwide SMR systems. The Motorola system is discussed below.

(1) CoveragePLUS. Motorola has announced the development of a nationwide two-way SMR voice, data, and position reporting service. Equipment and software changes will allow the over 900 nationwide Motorola SMR systems to be modified to accommodate this additional service and still serve their existing local customers. These modified SMR systems will be connected to a nationwide packet-data network. For redundancy, there will be more than one network hub, and each will be geographically separated. Fleet dispatchers will normally tie into the system via leased telephone data lines, which are connected to the nearest node of the packet network. This will be less expensive than connecting to the hub via leased lines. CoveragePLUS features an open architecture which allows interfacing with a variety of trucking industry specific software running on existing computer systems. An Apple Macintosh II computer equipped with eight megabytes of memory and a special software package can be used for freestanding connection with the network.

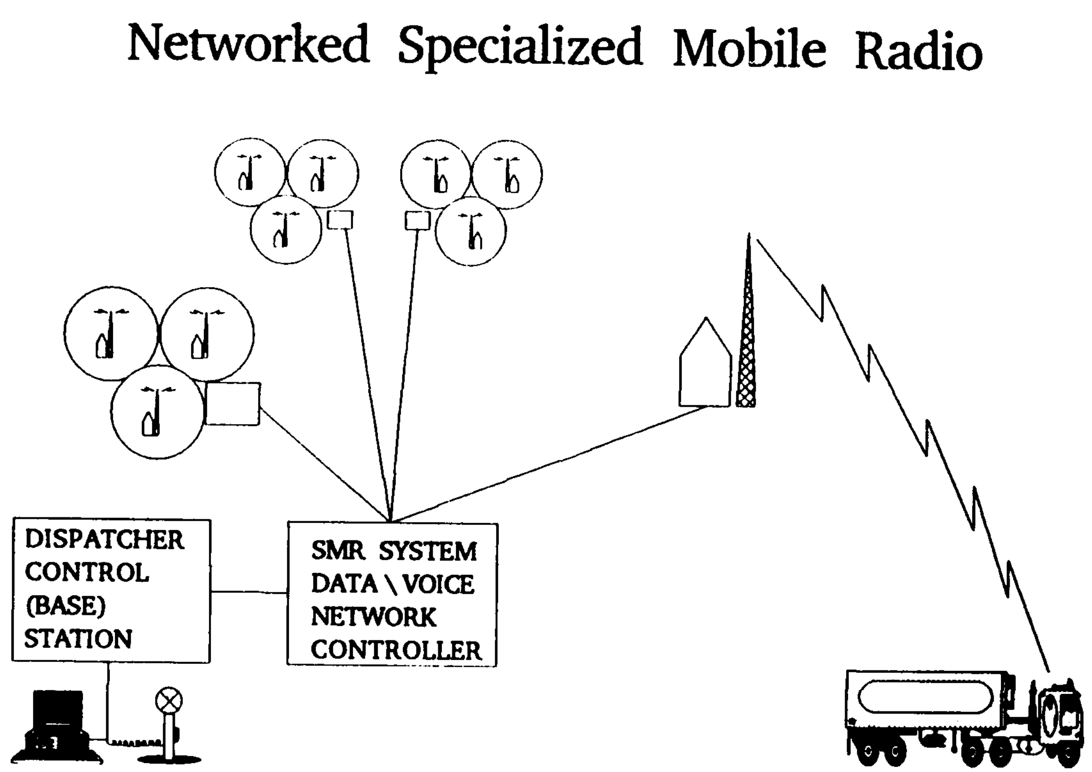

Figure 25. Networked Specialized Mobile Radio

CoveragePLUS is intended primarily to be a data system, but does have a voice capability. Voice traffic will move over the conventional telephone system directly between the SMR site and the dispatcher.

Conventional Motorola SMR transceivers are not capable of using the CoveragePLUS network, but will continue to be compatible with participating local SMR systems. CoveragePLUS radios are physically identical to regular Motorola SMR radios, but contain special software for network operation. Data are transmitted at 4800 bps. If additional capacity is required, data speeds can be increased to 19.2 Kbps.

CoveragePLUS mobile terminals will cost between $1850 and $3600. Equipment tiers comprise building blocks so customers can increase their communication capabilities as business conditions change. The base-priced radio will offer voice transmission, eight programmable status/message buttons, and various other conventional SMR functions. The mid-grade terminal adds a keyboard display unit. The top-of-the-line radio uses a Loran-C navigation receiver for position reporting. Because CoveragePLUS is based on Motorola's existing family of products, other configuration options are available, such as a 16 line by 40 column CRT terminal with a typewriter style keyboard. CoveragePLUS also features an open architecture which will allow connection of a variety of third-party equipment, such

as trailer sensors, refrigerated trailer monitors and controllers, on-board computer systems, and mobile fax.

In the roaming mode, CoveragePLUS radios scan and lock onto the nearest compatible system. Once logged into the system, the radio functions similar to a cellular telephone. When the radio moves into an area with a better signal, it will automatically change over to the new SMR site. For base and mid-level mobile radios, rough position information is displayed on the dispatcher's terminals by showing which SMR system the mobile unit is operating in. The Loran-C receiver in the top-priced radio will report the vehicle's location with the same level of accuracy as the Geostar II and Qualcomm systems.

Turning the CoveragePLUS roaming mode off will allow the operator to communicate on up to seven conventional SMR systems. A talk-group feature enables the user to select up to eight groups within a local SMR system.

The CoveragePLUS system will be first implemented in the Chicago-Detroit-Cincinnati transportation corridor. Additional coverage will be added in phases. Motorola has publicly stated that by the end of 1990 a user on interstates should never be out of communication for more than one hour. In most cases, users should enjoy seamless communications [Ref. 31].

4. <u>Costs</u>

a. Conventional SMR Equipment and Services

The American SMR Network Association (ASNA) estimates the cost for a five-channel, 800 MHZ system between $100,000 and $150,000, with an additional cost of $50,000 per additional five channels. It is estimated that costs for a 900 MHZ system are $50,000 more (for a ten-channel system) than an equivalent 800 MHz system. The cost of user equipment ranges from $750 to $2200 per mobile unit, depending on features and capabilities. The ASNA estimates that SMR system user costs are between $10 and $20 per month per unit for dispatch service from a local site [Ref. 29]. User fees in high demand areas, and value-added telephone and data services, may raise costs above this amount. Extended-area coverage (two or more remote SMR repeater sites) costs five to ten dollars per additional site. Networking or roaming arrangements, where users have access to 10-15 sites in a region, typically are charged by air-time usage, plus a $20 to $50 per month access fee. [Ref. 1:pp. 30-31]

b. Motorola CoveragePLUS

The base-priced radio, with voice capability, programmable status/message buttons, and other conventional SMR functions, costs $1850. The mid-grade terminal, with an added keyboard display unit, is priced at $2950. The Loran-C equipped unit is $3600. Cost for the stand-alone Macintosh dispatch computer and software is $19,500. The software is

available separately for $9500. Motorola will charge participating fleets a monthly fee of $35 per truck, which will cover <u>unlimited</u> location updates and status reports. Cost for text messages will be $0.05 for up to 240 characters. Telephone calls will cost $0.50 per minute for connection with the telephone network, plus any long-distance charges. [Ref. 31]

5. CoveragePLUS System Issues

Motorola is capable of economically building a nationwide SMR network because more than 900 of its stand-alone SMR sites are already supported by a user base. As such, Motorola only has to recover the incremental cost of networking existing SMR sites and building new sites to bridge critical highway coverage gaps. In contrast with dedicated-satellite systems, technological risk is minimal, SMR sites can be easily repaired, and additional units of capacity added at a low cost. The use of fiber-optic packet-data networks and a 4800 bps to 19.2 Kbps per channel transmission rate gives the system a large user capacity.

CoveragePLUS transceiver costs are minimized due to existing production economies of scale and the use of proprietary software to modify the function of the radio. As discussed in Chapter III, the $35 monthly fee and unlimited status messages allow routine user information to be conveyed at a lower unit cost than any other existing mobile satellite or nationwide mobile-communication system. For voice

communications, CoveragePLUS will be less expensive than roaming cellular telephone. Although the $0.50 per minute local access fee is competitive with cellular per-minute charges, users will avoid paying the monthly Follow-me Roaming fees and daily out-of-area access fees. At this rate structure, heavy users of roaming cellular telephone may find it economical to switch to CoveragePLUS simply for voice communications.

Within its service areas, CoveragePLUS will provide almost every type of communication supplied by existing and proposed satellite systems, meteor-burst systems, and terrestrial networks. From a user's standpoint, the main objection to CoveragePLUS may be the lack of universal coverage.

G. MOBILE DATA SYSTEMS

1. Background

Mobile data systems are one of the latest entrants to the mobile communication field. Unlike cellular radiotelephone and specialized mobile radio, which are designed primarily for voice, mobile data systems (MDS) are optimized for the transmission and routing of data messages. A typical voice dispatch lasts between 20 and 30 seconds. The same information can be sent digitally in 0.8 seconds or less. When compared to a voice system, dispatchers using MDS can handle five to 25 times the number of drivers. This is

because the digital messaging eliminates time-consuming data transcription, reduces non-essential communications, and enables the automation of certain routine functions. Mobile data systems are not limited to vehicle dispatching. Mobile and portable rf terminals extend the reach of computer networks and allow data entry from anywhere within the coverage area.

Mobile data systems are spectrally efficient. Messages that would require the exclusive use of a frequency under a system designed for voice, plus the additional time the channel was blocked from use while the call was being set up and taken down, can be sent directly onto a data channel containing the messages of many other users. With a capability of handling 6000 to 9000 messages per hour, the effective capacity of a MDS is over 20 times that of a mobile voice-dispatch channel. The efficient use of the rf spectrum and the high system throughput permits many users to be served at a low individual cost.

In 1988 there were over 30 companies developing and marketing mobile data terminals, software, and complete data-only systems. Private mobile data applications range in scope from simple local systems, such as police and taxi dispatch, to large nationwide-networked systems. Current mobile data systems use incompatible proprietary signaling formats. This limits the user's options when buying additional equipment. [Ref. 1:pp. 43-47]

The two largest private mobile data systems are operated by IBM and Federal Express. The IBM system was built by Motorola, and was initially designed for service dispatch and repair-parts ordering. The system cost over $100 million, and uses over 1000-networked base stations to cover more than 8000 cities and towns in all 50 states. All base stations are connected via a packet-switched data network. The system is used by about 16,000 IBM and 2000 ROLM service personnel, and is being expanded for public use [Ref. 32]. When compared with prior costs and methods, IBM's mobile data system paid for itself in less than two years. IBM's original two applications have grown to over 30. An additional cost avoidance of approximately $500 million is projected over a ten year period [Ref. 1:p. 45].

The Federal Express system was manufactured by Mobile Data International (purchased by Motorola in 1988). Federal Express has over 16,000 vehicle terminals and 400 portable radios. Drivers are digitally dispatched and report status to 14 regional centers [Ref. 1:p. 45].

<u>Public</u> mobile data systems are also being implemented. The concept is similar to SMR, where users can buy or lease terminals and subscribe to a system. This permits organizations to use the service without having to get FCC licenses and go to the expense to build and operate a dedicated system. Public MDS's also generate economies of scale. Systems can have wider geographic coverage and greater

capabilities than many single firms could afford with a private system.

At least two companies are actively pursuing public mobile data systems. Ericcson has plans for a 50-city MDS in the 900 MHz band [Ref. 33]. Motorola operates public mobile data systems in Los Angeles, Chicago, and New York, and has teamed with IBM to form the ARDIS Corporation. The ARDIS system melds Motorola's three public mobile data systems with the IBM network described above.

2. General System Configuration and Operation

In a basic private MDS, communication to and from the dispatcher's console flows through a computer which controls the overall operation of the system. The computer's input and output are connected to a VHF or UHF transceiver. Data signals can be sent through a local antenna or be routed through a repeater to increase the communication range. Mobile data has also been adapted for use over public and private SMR systems. SMR channel access and control is identical to the SMR voice systems discussed above.

A more complex public mobile data system is shown in Figure 26. Many different users communicate over common frequencies by using a multiple-access protocol. Signals to and from the terminals move through a radio base station which is connected to the network control center. The network control center governs the operation of the system and serves as the communications gateway. Data moves from the gateway to

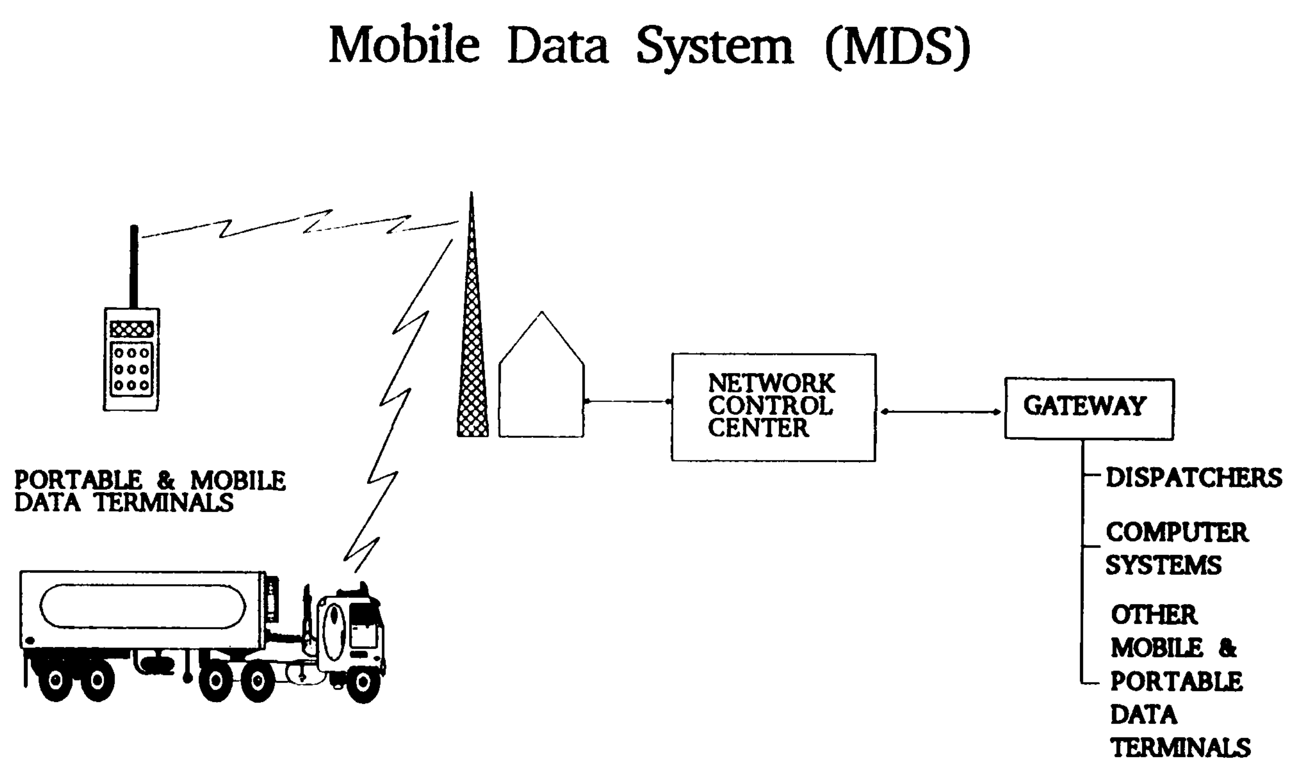

Figure 26. Mobile Data System (MDS)

dispatch and other computer systems via packet-switched networks or dedicated telephone lines. [Ref. 1:p. 44]

MDS hardware and software requirements vary according to the coverage area, number and average length of messages, type and quantity of terminals, and degree of required building penetration. Portable handheld terminals which will be carried deep into buildings complicate the MDS configuration. This is because building absorption can reduce the transmitted and received signal strength by a factor of 30 to 100 times (15 to 20 dB). This problem is made worse by the low transmit power (five watts or less) and the inefficient antenna systems used in handheld terminals. Mobile-vehicle terminals, with their higher power transmitters and more efficient antenna systems, do not experience this problem as severely as handhelds. For example, only five or six base stations are necessary to provide message communications to and from a fleet of mobiles in the Chicago metropolitan area. If the requirement is raised to include complete in-building portable-terminal coverage, 40 or more base stations are required [Ref. 34].

For metropolitan-area systems which require more than one base station, a simple approach to the problem is to use a separate set of frequencies for each base station. This poses the difficulty of having to switch frequencies when moving from one coverage area to another. Very few public or private organizations have this many frequencies allocated to

them in one geographical area. This arrangement is also an inefficient use of the rf spectrum. Additionally, some method is required to track the mobile terminal's position in order to know to which base station to route an outbound message.

These problems can be reduced by using a simulcast system, where all base-station transmitters simultaneously broadcast the outbound messages to the terminals. The difficulty with a simulcast system is that message throughput can be limited by the outbound channel capacity and the total number of required frequencies is cut by only approximately 50%.

A system of frequency reuse can be applied to overcome the above limitations. Rather than occupying many different frequencies, only one or two are used. This is permitted by the number of base stations, the limited power of handheld terminals, and by controlling the strength of mobile terminal transmissions. System logic must be designed to deal with the receipt of the same signal at more than one base station. The system must also be able to track the location of the mobile unit so that messages to terminals are only routed through a single base station. To prevent mutual interference, an inhibit process must be used to cause neighboring base stations to yield the outbound frequency to each other and prevent collocated terminals from transmitting at the same time. [Ref. 34]

3. Motorola Data Radio Network

The Data Radio Network system is designed to provide wide-area metropolitan coverage for a large number of portable and vehicle users. This system is illustrated in Figure 27. About 1500 portable terminals can be operated on a single pair of rf channels in a typical city, depending on traffic volume, message length, and location of the base stations.

a. Basic Operation

Multiple-base stations and computerized control allow a single pair of 25 KHz wide channels (generally at 810 and 855 MHz) to be continuously reused across the covered territory. The use of separate inbound and outbound channels increases system capacity by allowing the base station to simultaneously send and receive. Rf messages are sent at 4800 baud using frequency-shift keying. Each message can contain up to 760 bytes of data. Longer messages can be chained together in separate transmissions.

Messages sent from a terminal are received by one or more base stations and demodulated. The information stream is sent to the channel controller, where the message is decoded, errors are detected and corrected, and the data are prepared for landline transmission to the central control processor. Data and control signals move over the landlines at 2400 baud. The difference between the 4800 baud rf speed and the landline speed is due to the additional error correcting code used on the rf channel.

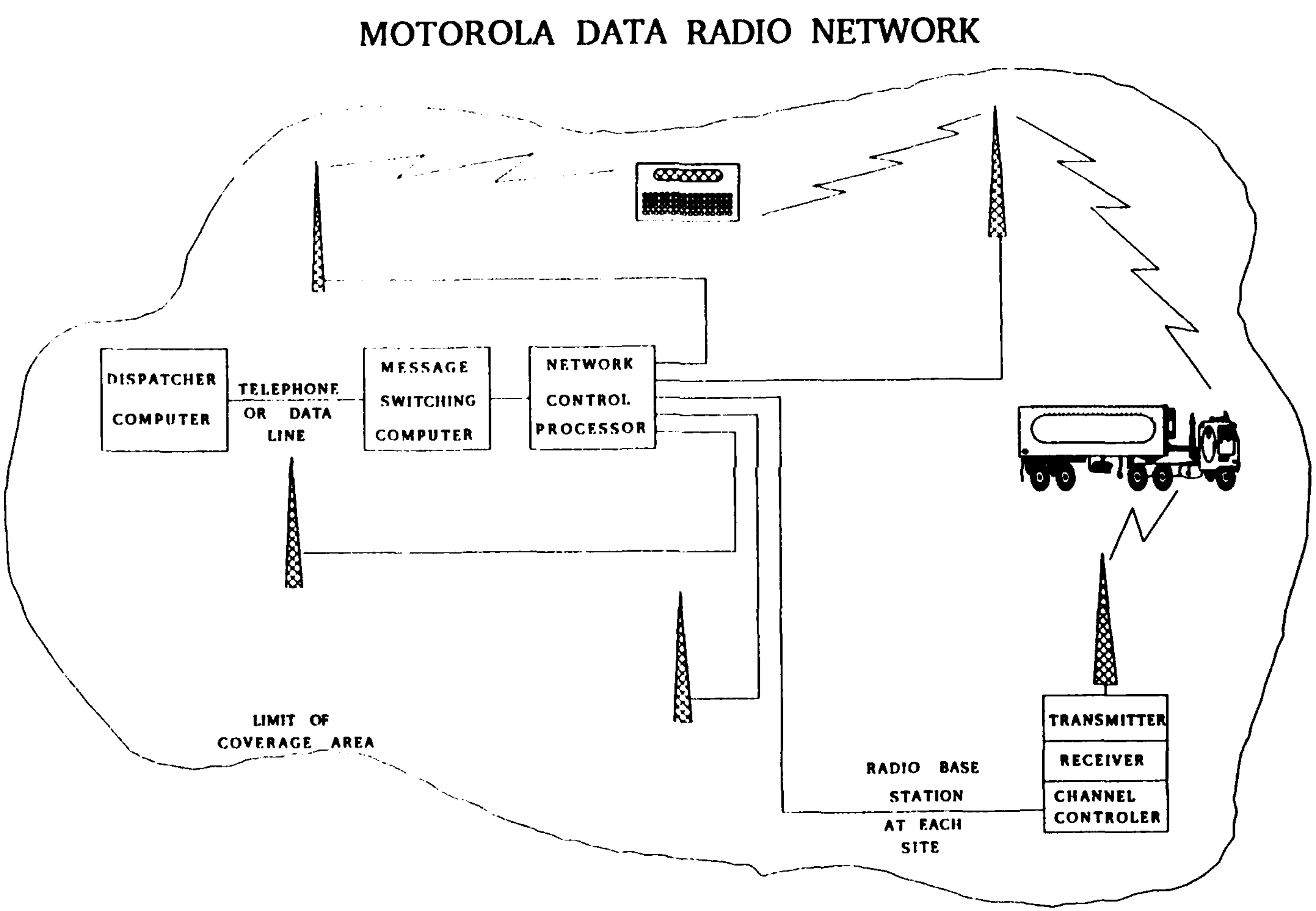

Figure 27. Motorola Data Radio Network

The network control processor governs up to 60 base stations. The network processor eliminates duplicate messages by comparing each received message's terminal identification number and its time of arrival with prior messages of the same terminal identification. Messages are subsequently sent to the message-switching computer, where the terminal identification number is used to route the data to the proper destination.

Messages to a mobile or portable terminal are formatted with the appropriate terminal identification and routed through the message-switching computer. They are passed to the network control processor, where they are sent to the most appropriate base station. The base-station channel controller prepares the message for transmission by adding error detection and correction coding. The message is then routed through a 45-watt base-station transmitter. [Ref. 35]

b. Metropolitan Area Network Management and Interference Prevention

Each time a transmission is received, the base-station channel controller measures the received signal strength and forwards this information to the metropolitan network-control processor along with the message. The control processor combines the signal strength with network topology information to determine the best base station for return communications. If no recent communications have occurred, or

the terminal has travelled considerably since the last communication, a search algorithm is used to find the terminal. Once the base station determination has been made, the outbound message is scheduled for transmission.

To prevent base-station transmissions from interfering with each other, the metropolitan network-control processor prohibits simultaneous collocated transmissions. System logic also reduces the chance that collocated terminals will interfere with each other. When receiving an rf message, the channel controller will send an inhibit command on the outbound channel. In the event that a base station is already transmitting a message, a periodic inhibit command is inserted into the outbound-data stream. In either case, the inhibit command is stopped when the base station controller is finished receiving the inbound message.

Both the channel controller and the mobile terminal perform forward-error correction. Messages that exceed the error correcting code capability are detected by a cyclic redundancy check (CRC). CRC errors cause either a negative acknowledgement or no response from the intended receiver. Messages not immediately acknowledged or negatively acknowledged will be retransmitted up to three times. [Ref. 35]

c. Nationwide Networking

To form the ARDIS system, the Motorola Data Radio Network control processors have been interconnected with IBM's

system via a packet-switched network. To provide redundancy, the network is managed by two operations centers which are located in Illinois and Kentucky. The operations-center computers use software and hardware to run continuous diagnostic tests of the system. Should problems occur, data messages can be rerouted if the difficulties are not correctable by the remote repair capabilities built into the system. The network operators can also dispatch repair personnel if necessary. [Ref. 32]

4. Costs

Production economies of scale do not yet apply to mobile data equipment because this mode of communication is relatively new. As a result, small private systems using SMR or two-way voice frequencies may cost between $5000 to $10,000 plus $1500 to $3000 per terminal. More sophisticated systems with additional capacity and features start at around $100,000 for the software and network controller. Equipment prices could drop by around 50% with a large enough market [Ref. 1:pp. 46-47].

Subscription to the Motorola Digital Radio Network costs a minimum of $30 per month. Communication charges are $0.10 per 240 characters during the peak hours between seven a.m. and six p.m. During off-peak hours this charge is reduced to $0.05. Depending on features and quantities, rf modems are available for between $550 to $1500. Mobile terminals cost about $1600 to $3500, depending on features.

Handheld portable keyboard display terminals (KDT) cost up to $3800 each.

The one-time charge for microcomputer software and connection with the DRN is approximately $2000. Software, hardware, and connection costs for mini- and main-frame computers are around $3000. Charges for connection with DRN message switching computer are the user's responsibility. If dial-in service is used then an additional $5.70 an hour is assessed.[19]

Since all DRN and ARDIS sites are connected via a fiber optic network, there is no long-distance charges for communication with out-of-area mobile or portable terminals. Additional information on the cost of ARDIS equipment and services was unavailable at the time this thesis was written.

5. Future Developments

In a controversial decision, the FCC in 1988 reallocated the lower two MHz of the 220-225 MHz VHF amateur radio band to advanced-technology narrow-band land-mobile communications. This was done because there are few vacant nationwide frequencies available in the land mobile band. Also, the contemplated narrow-channel spacing (five KHz) is incompatible with existing mobile VHF and UHF channel spacing. This allocation is intended to spur the development and

[19]Telephone conversation between Mr. Ed Downey, Marketing Manager, Motorola Data Radio Networ, and the author, 7 September 1989.

implementation of new spectrum-efficient narrow-band digital voice and mobile data systems. Nationwide frequency assignments will enable large companies, such as United Parcel Service, to operate their extensive vehicle fleets on a common set of channels. Likewise, nationwide frequencies will be made available for mobile data systems. [Ref. 36]

H. PAGING

1. Background

Of all the radio communications technologies, paging is the most simple and straightforward. Pagers are receive-only devices. Each system pager is programmed with a unique digital-identification code. Receipt of this code will activate the pager. Pagers come in four main groups: tone-only, numeric display, alphanumeric, and tone-voice. Tone-only pagers are the simplest, but the recipient doesn't know who called. Numeric-display pagers are capable of displaying the area code and telephone number of the person making the page plus have space left over for at least one extra digit. This allows the use of code numbers to convey additional information. A touch-tone telephone is used for input. Alphanumeric-display pagers are controlled with special terminals or a personal computer and a modem. Connection with the paging company is via the telephone system. Depending on the type of system, messages can be up to several thousand

characters long. Tone-voice pagers provide a tone followed by a ten-second voice message.

Digital paging is spectrally efficient. Tone-only paging systems support about 100,000 pagers per channel. Numeric-display systems can accommodate about 50,000 users per channel. This contrasts with the limited 1500 pagers per channel in a tone-voice system. [Ref. 1:pp. 24-25]

Because digital paging is so efficient, many companies cover regional areas by simultaneously broadcasting a page-over data links to multiple transmitters. For example, one paging system provides coverage of the more populated areas of California and Nevada. Within the blanketed area, a user will receive the page regardless of location. Several companies have recently formed nationwide networks, and are continuing to expand coverage by adding additional transmitter sites. Metrocast has expanded coverage into England, and has plans for expansion into Japan and the rest of Europe [Ref. 37].

Paging's major limitation is that the sender of the page is not notified by the system when the page was received.

Radio paging is a $1.7 billion industry which is growing at an annual rate of between 7% and 9%. Hardware costs are declining at around 7% a year, and service fees are falling at a 3% rate. A modest paging operation, consisting of a paging-system controller, transmitter, antennas and pagers, ranges in cost from $150,000 to $250,000. [Ref. 38]

2. Configuration and Operation

a. Local and Regional Systems

Figure 28 illustrates a local and regional paging system. The input device, a telephone or personal computer, is connected to the paging-system controller via the telephone system. Pagers are accessed in one of two ways. The pager can have a unique individual telephone number or the identification number of the pager can be keyed in on a touch-tone phone or other device. The information to be transmitted is sent by the paging-system controller to the local transmitter, and if part of a regional system, out over a data link for wide area simulcast.

b. Nationwide Systems

Figure 29 shows the basic structure of nationwide-paging systems. The following description of the Metrocast, Cue, and National Satellite Paging systems illustrates the different way pages can be distributed and the additional services which are provided.

The Metrocast system is linked via terrestrial networks to conventional UHF-paging transmitters positioned throughout the U.S. Pages are routed by a computer to the user-programmed remote-transmission site. The computer can be programmed to store the messages for later telephone retrieval if the user will be out of a covered area. Messages can also be stored for up to 99 hours when transiting between coverage areas, and at the end of a preset time be received in the

Paging Systems

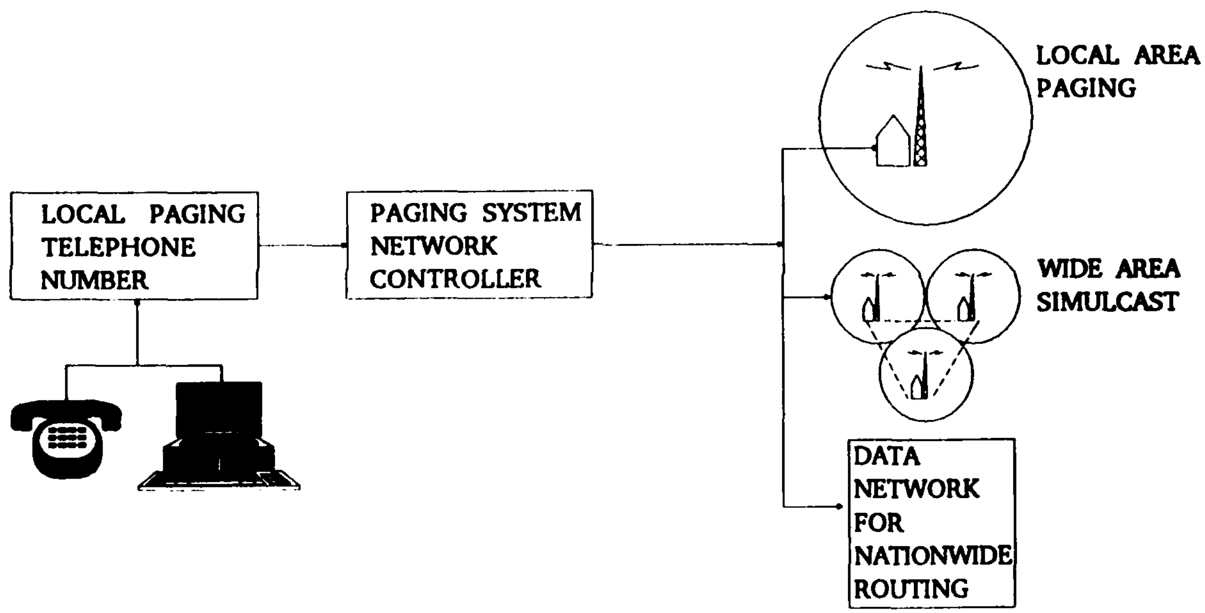

Figure 28. Paging Systems

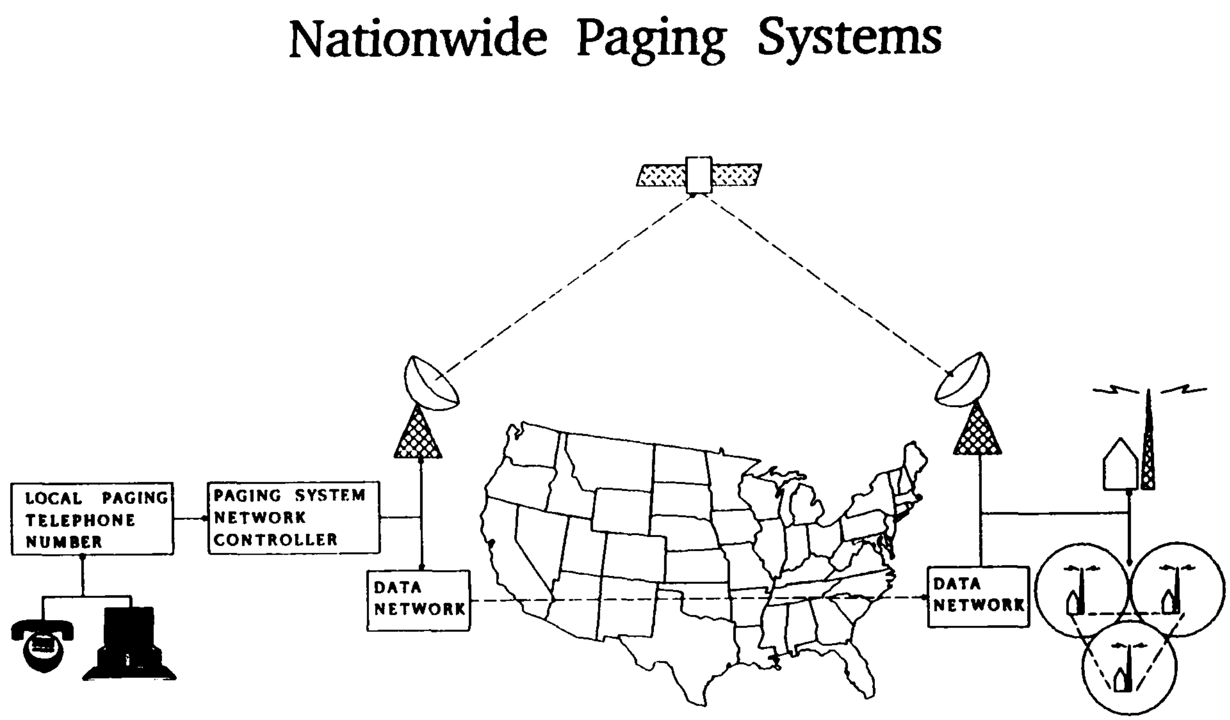

Figure 29. Nationwide Paging Systems

destination area. Metrocast pagers are capable of receiving numeric and alphanumeric messages.[20]

Cue Paging uses the Westar Four satellite instead of the telephone network to perform simultaneous nationwide-page distribution. Area paging transmitters are commercial FM broadcast stations which receive the Westar Four downlink and rebroadcast the page via subsidiary communication authorization (SCA). SCA is a method of modulating additional communications signals onto a conventional FM broadcast. These signals are not detectable by a conventional FM broadcast receiver [Ref. 39:p. 481]. Cue has over 100 FM broadcast stations in their network, ranging in frequency from 87 to 108 MHz. Cue pagers scan and lock onto the strongest Cue SCA signal. When coverage is lost, an audible tone and display alerts the user to call the paging system computer, via a toll free number, to check for any missed messages [Ref. 40]. Messages can be up to 12 digits long. Cue-Enhanced Wide Area Service-Level coverage areas as of the first half of 1989 are illustrated in Figure 30 [Ref. 41].

National Satellite Paging also uses a satellite to distribute its messages, but has its own dedicated-paging transmitters located in 77 of the top 100 population centers. Pages up to 20 digits long are sent to all transmitters simultaneously. The pager is smaller and lighter than others

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[20]Telephone conversation between Ms. Anita Couch, Metrocast Corp., and the author, 6 February 1989.

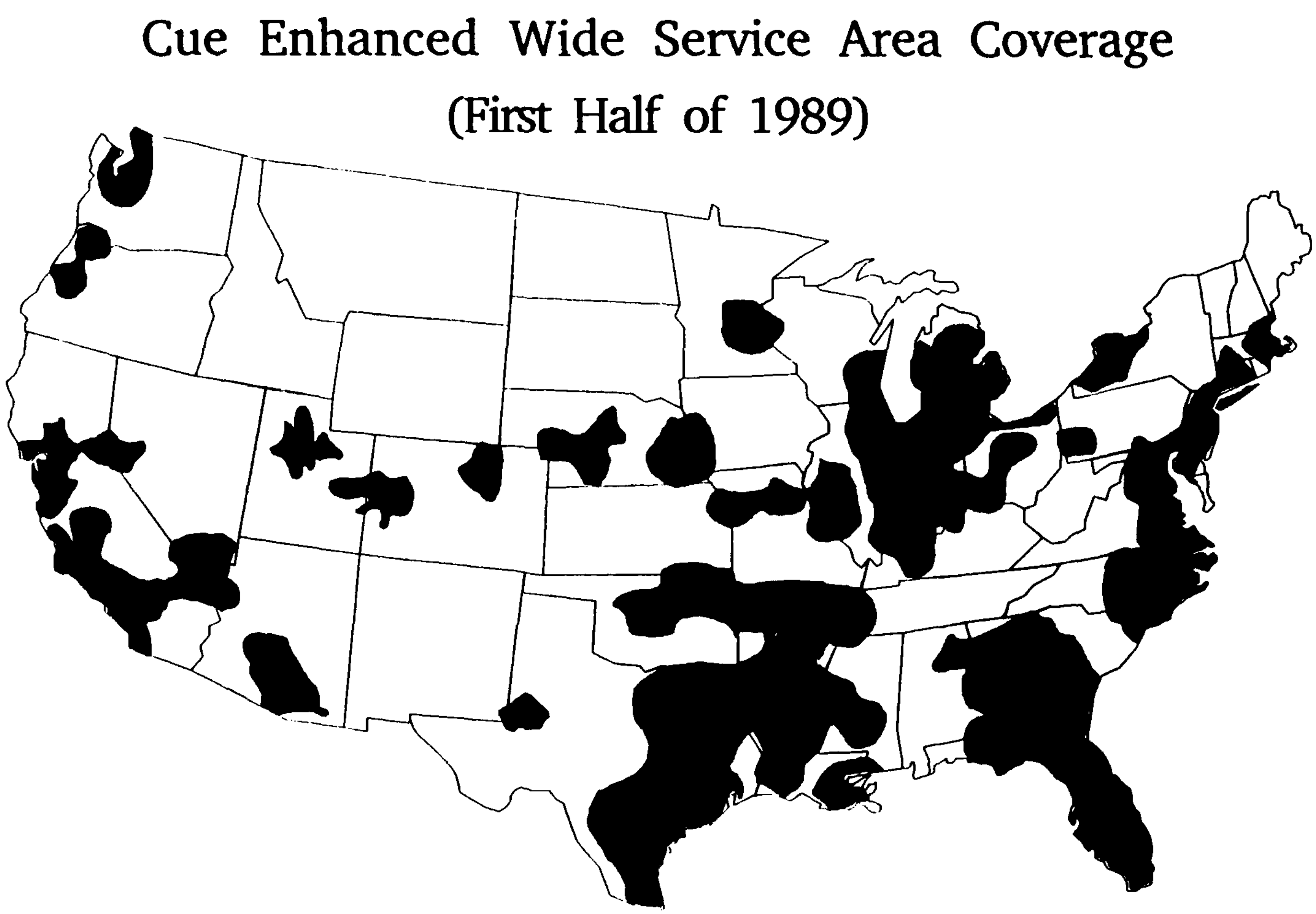

Figure 30. Cue-Enhanced Wide Service Area Coverage (First Half of 1989)

because it does not require circuitry for frequency scanning. [Ref. 42]

Each of these nationwide-paging systems offers voice-mail services. The sender telephones the paging system computer, identifies the pager number via touchtone keypad, and records a voice message. The system then broadcasts a page, and the recipient then calls the paging-system computer. The appropriate codes are entered via the telephone keypad and the message is retrieved.

3. Capabilities

Almost 300 paging channels are available for use in four bands, ranging from low-band VHF (30-50 MHz) to 900 MHz UHF. FM sub-carrier paging, which uses existing FM-broadcast stations, has low capital costs and wide-area coverage, but building penetration is poor. 900 MHz paging has higher capital costs, shorter coverage, but superior building penetration. VHF and UHF (450 MHz) systems are somewhere in-between. [Ref. 1:p. 25]

4. Costs [Ref. 1:p. 24]

a. Purchase Costs

a. Tone only: $80-$200.

b. Numeric display: $250-$350.

c. Tone and voice: $125-$200.

d. Alphanumeric display: $275-$500.

e. Nationwide: $250 to $500.

b. Monthly Service Charges

Service charges depend on the area of the country and the amount of use. For local areas:

a. Tone only: $7-$15.

b. Tone voice: $20-$25.

c. Numeric display: $10-$20.

d. Alphanumeric: $12-$30.

For wider regional coverage, $15 to $20 are added to these rates. Nationwide numeric paging costs about $50 per month. Nationwide pagers are frequently leased, with the total monthly communication and equipment charges ranging from $50-$100.

5. <u>Future Developments</u>

With the continuing miniaturization of components, particularly through very large-scale integrated (VLSI) circuits, pagers continue to become more sophisticated and smaller. Message storage capacity will continue to increase, and pagers will become more than just personal signaling devices. Wristwatch pagers have been developed by AT&E (San Francisco) and Motorola. Both firms will market these pagers for around $300. [Ref. 38]

British Telecom Mobile Communication has developed and tested a system which allows conventional alphanumeric pagers to be used for direct satellite paging. A small L-band satellite-receive unit and frequency down converter are installed in a vehicle. The pager is inserted into a slot,

where the down-converted satellite signal is inductively coupled to the pager. A small printer is built-in to provide the driver with a hard copy of the message. Subscribers to this expanded service will have their pages routed by the paging-system controller to both the satellite and conventional terrestrial networks. The standard alphanumeric pager can be removed and used in the conventional way when within terrestrial paging coverage. [Ref. 43]

I. SUMMARY COMPARISON OF MOBILE COMMUNICATION SERVICES AND TECHNOLOGIES

Tables 1 and 2 briefly summarize and provide a comparison of the system characteristics described above.

J. CONCLUSIONS

The advanced technologies which enable mobile satellite communications are also being applied to terrestrial mobile communications systems. This increases the utility and efficiency of ground-based systems. For users who do not require universal geographic coverage, these advanced ground systems may provide the same types of service and be more cost effective than satellite systems.

The major challenge to SMR and mobile data systems is the lack of universal technical standards, such as with cellular telephone. This may limit nationwide SMR and mobile data systems to large companies, such as Motorola, who have the financial ability to implement these systems on their own.

With continuing technological development, all types of communications systems will continue to increase in complexity and ability to provide higher levels of service and performance.

TABLE 1

COMPARISONS OF MOBILE COMMUNICATION SERVICES AND TECHNOLOGY

COMPARISON	Geostar 2.0	Geostar 2C	Geostar 3.0	OmniTRACS	AMSC/TMI	Meteor Burst
VOICE SERVICES	None.	None.	Limited voice through use of speech synthesis chips.	None.	Variety of nationwide digital voice services.	None.
DATA SERVICES	Nationwide one-way data and positioning.	Nationwide two-way data and positioning.	Nationwide two-way data and positioning. High capacity.	Nationwide two-way data and positioning.	Nationwide two-way data and positioning.	Nationwide two-way data and positioning. Short messages with several minute responses.
COVERAGE AREA	Nationwide, degraded performance when line of sight to satellite is blocked.	Nationwide, degraded performance when line of sight to satellite is blocked.	Nationwide, degraded performance when line of sight to satellite is blocked.	Nationwide, degraded performance when line of sight to satellite is blocked.	Nationwide, degraded performance when line of sight to satellite is blocked.	Nationwide. Effects of obstructions less severe.
ROAMING	Not applicable.	Not applicable.	Not applicable.	Not applicable.	Not applicable.	Not applicable.
POSITION REPORTING	Loran-C	Loran-C	Satellite ranging.	Loran-C or satellite ranging.	Loran-C, GPS.	Loran-C

TABLE 1 (CONTINUED)

COMPARISON (Continued)	Geostar 2.0	Geostar 2C	Geostar 3.0	OmniTRACS	AMSC/TMI	Meteor Burst
AVERAGE PRICE OF SUBSCRIBER EQUIPMENT IN 1990	$3,300	$4,100	N/A	$4,100	N/A	$2,000
SERVICE CHARGES	$45 per month for one transmission per hour.	$45 per month for one transmission per hour.	Should approximate existing rate structure.	$35 per month, $0.05 per message $0.002 per character.	N/A	$35 per month plus $0.10 per message.
ISSUES	One-way restriction limits utility. Can be combined with a nationwide pager.	Interim system until Geostar 3.0 is operational.	Large capital costs. Provides very accurate position information without an external navigation system.	Does not require risk or capital expenditure of satellite construction and launch.	Large capital cost Broad base of data and voice applications.	Short message time delay up to 15 min. No need for expensive satellites. Conventional technology and low technical risk.

TABLE 1 (CONTINUED)

COMPARISON	Cellular Telephone	SMR	Mobile Data	Paging
VOICE SERVICES	High quality mobile service. Not suited for group dispatch of vehicles.	Primarily a voice service. Mobile telephone also available. Used for dispach.	Very limited, causes major reductions in system capacity.	One-way only service. Voice paging is not widely used. Some nationwide paging services have a voice mail option.
DATA SERVICES	Can provide fax and data communicat with special modems. Expensive.	Circuit switched data using modems and terminal.	High data throughput, quick response times, advanced features.	Tony-only, or digital display with numeric or alpha-numeric messaging.
COVERAGE AREA	Expanding as RSA's become operational.	Available in all towns of any size. Regional and national networks in implementation stage.	Limited to the more dense population centers. ARDIS and other wide area networks in implementation stage.	Available in all towns of any size. Nationwide systems cover all major population centers.
ROAMING	Automatic roaming for outbound calling. Inbound calling can be cumbersome. New standards being developed for inter-system handoffs.	Limited, non-automatic outbound roaming. New networks will be two-way automatic.	Wide area networks will feature automatic roaming within their coverage areas.	Nationwide and regional networks permit roaming in the more densely populated areas.
POSITION REPORTING	Loran-C or coverage area of the cell.	Loran-C or the coverage area of the SMR site.	Loran-C or the local system coverage area.	N/A

TABLE 1 (CONTINUED)

COMPARISON (Continued)	Cellular Telephone	SMR	Mobile Data	Paging
AVERAGE PRICE OF SUBSCRIBER EQUIPMENT IN 1990	$300 - $800	Conventional: $750 - $2,200. CoveragePLUS: $1,850 - $3,600	Private system: $2,000 - $3,000. Data Radio Network: $2,500 - $3,500	$80 to $500, depending on features.
TYPICAL SERVICE CHARGES FOR METROPOLITA COVERAGE.	$7.50 - $20/mo. plus $0.20 - $0.90 per minute.	One repeater: $10 - $20. Two or more, add $5 to $10 per repe	Data Radio Network: $30 per month, plus $0.05 - $0.10 per 240 characters.	$7 to $30 per month, depending on the type and coverage of service.
TYPICAL SERVICE CHARGES FOR MULTI-CITY COVERAGE.	Hellyer: $22 per month, $4.95/mo. roaming access, $2.00/day per roaming area, around $0.60 per minute, plus any long distance charges.	CoveragePLUS: $35 per month, $0.05 per 250 character message, $0.50 per minute for voice calls, plus any long distance charges.	Same as above.	Regional: $25 - $50 per month. Nationwide: $50 - $75 per month.
ISSUES	Lack of coverage outside of the more densely populated areas. More RSAs being added. Digital conversion in saturated areas.	Lack of coverage outside of denser populated areas. Lack of standards	Highly efficient for large volumes of traffic. ARDIS network will cover most of the denser populated areas.	Inexpensive. Not able to verify if recipient has received the page.

III. <u>USER COST COMPARISON</u>

A. INTRODUCTION

The characteristics, features, and levels of service provided by each type of communication system are only one facet to be considered. This chapter examines and compares user costs for local, regional and nationwide mobile communication services.

B. USER COST MODEL

1. Limitations

The fully-allocated operating cost categories described below are illustrated in Figure 31 and are limited to mobile-equipment amortization, fixed monthly-service charges, and variable communication charges. Expenses for dispatch equipment are not included because of the various types of computer hardware which can be used. Installation and maintenance are also not included because of the difficulty in defining these costs.

The model views the fully-distributed operating costs as monthly cash outflows, exclusive of taxes and depreciation. Aside from mobile-equipment amortization, no allowance is made for the time value of money. Inflation is not included. No attempt is made to quantify opportunity costs or the operational effects associated with each type of system. The fully-allocated cost figures are estimates only. Actual costs will vary depending on the application and the method of

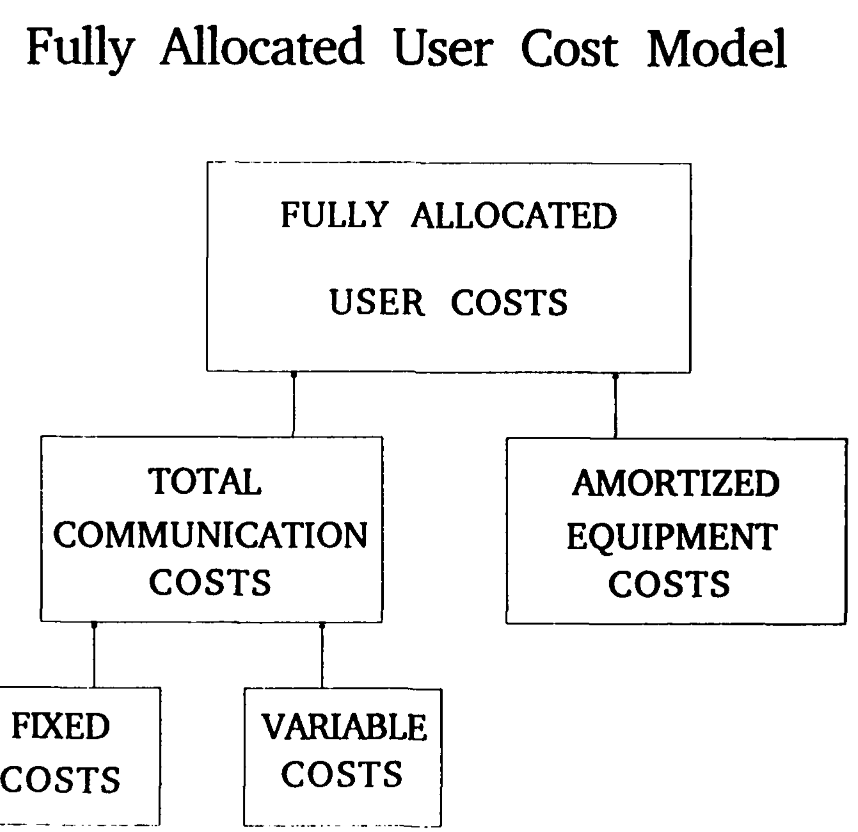

Figure 31. Fully-Allocated User Cost Model

operation. However, these monthly cost figures are sufficient for illustration, comparison and discussion.

Items excluded from this analysis, such as tax effects, rate of return, efficiency gains, cost reductions, etc., are modeled in Chapter IV for the currently operating Geostar and Qualcomm satellite systems.

2. Overall Assumptions

The cash flow analysis attempts to be conservative. Although most of the equipment probably has a working life of over five years, it is amortized over a five-year period to account for technological obsolescence. To account for the time value of money, monthly equipment expense is determined by amortizing the equipment purchase price at a 12% cost of capital. This raises monthly expenses by $5.58 for each $1000 of equipment purchase cost.

To simplify the analysis, the daytime long-distance rate (weekdays eight a.m. to five p.m.) is used in all cost calculations. Inbound long-distance telephone calls to the dispatcher use the WATS service area five (approximately 2500 to 3000 miles) rate, discounted at 15% under the AT&T 800 Readyline Service plan. This yields an inbound long-distance charge of approximately $0.25 per minute. Outbound calls from the dispatcher use the AT&T PRO AMERICA I plan step ten rate (about 3000 miles), discounted at 15%. This equates to an outbound charge of approximately $0.35 per minute. [Ref. 44]

For those mobile communications systems which use a network management facility (NMF), it is assumed that the dispatcher accesses the central computer via the telephone system once an hour to receive position updates and to send and receive messages. The use of very small aperture terminals (VSAT's), packet-switched networks, and leased telephone lines to communicate with the NMF are excluded from the analysis except where required by specific systems. This is because of the range of costs for these services and the need to reduce the quantity of output.

Communication between the dispatcher's computer and the NMF is at 2400 baud, and digital messages are assumed to be 50 characters long. Fleet size is assumed to be 100 equipped vehicles. The calculated connection time with the NMF is doubled to account for variable data upload, download, and switching times.

It is assumed that vehicles are operated 21 days per month. To perform the sensitivity analysis, the total number of communications between the driver and dispatcher are stepped from one to five per operating day. Since most of the information flow is from the vehicle to the dispatcher, all long-distance telephone voice communications are assumed to be initiated by the driver. Although voice conversation times will be variable, they are fixed at one and three minutes to simplify the analysis. With one-way systems, such as nationwide paging and Geostar 2.0, the number of required

phone calls is reduced by 50%. Total fully-allocated costs per month are rounded to the nearest dollar.

3. Baseline Cost Comparison

The use of the public telephone system serves as the baseline for communication cost comparisons.

a. Long Distance [Ref. 44]

a. Cost for a one minute call equals $0.25.

b. Cost for a three minute call equals $0.75.

c. Cost per month:

Number of Calls per Operating Day

1	2	3	4	5
One Minute per Call				
$5.25	$10.50	$15.75	$21.00	$26.25
Three Minutes per Call				
$15.75	$31.50	$47.25	$63.00	$78.75

b. Local

a. Cost for a call is $0.25, no time limit.

b. Cost per month:

Number of Calls per Operating Day

1	2	3	4	5
$5.25	$10.50	$15.75	$21.00	$26.25

C. EQUIPMENT AND SERVICES[1]

1. <u>Geostar System 2.0</u>

a. Average equipment price of $3375 amortized equals $75.00 per month.

b. Monthly minimum service charge of $45.00. Users are entitled to the equivalent of one position report and message per hour (approximately 740 per month). Extra messages are $0.05 each. The number of text messages and position reports are within the $45.00 minimum charge.

c. Pro-rata charge for dispatcher connection with the NMF is $2.00.

d. Total monthly fixed cost equals $122.

e. Inbound long-distance charges for communication between the driver and dispatcher are reduced by 50%.

f. For one-minute calls, the telephone charges for one to five calls per operating day range from approximately $3 to $13 per month. Total monthly communication costs vary between $125 and $135.

g. For three-minute calls, the telephone charges for one to five calls per operating day range from approximately $8 to $39 per month. Total costs vary between $130 and $161 per month.

2. <u>Geostar System 2.0 Combined with Nationwide Paging</u>

a. Average equipment price of $3375 amortized equals $75.00 per month.

b. Monthly minimum service charge of $45.00. Users are entitled to the equivalent of one position report and message per hour (approximately 740 per month). Extra messages are $0.05 each. The number of text messages and position reports are within the $45.00 minimum charge.

c. Pro-rata charge for dispatcher connection with the NMF is $2.00.

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[1] Cost information sources are listed in Chapter II.

d. Monthly service charge and rental of $60.00 for nationwide paging.

e. Total monthly fixed cost is $182.

3. Geostar System 2C

a. Average equipment price of $4100 amortized equals $91.00.

b. Minimum monthly service charge of $45.00. Number of text messages and position reports are within the $45.00 per month minimum charge.

c. Pro-rata charge for dispatcher connection with the NMF is $2.00.

d. Total cost per month equals $138.

4. Geostar System 3.0

a. It is assumed that the Geostar 3.0 equipment price ceiling will be equal to that of existing System 2C equipment, or $4100. When amortized this equals $91.00 per month.

b. From RDSS filings with the FCC, it is assumed with large production economies of scale the cost of user terminals could drop to approximately $1000 or lower. [Ref. 8:p. 12]. $1000 amortized equals $22.00 per month.

c. It is assumed the monthly minimum service charge will be $45.00, and that users will be entitled to the equivalent of one position report and message per hour (approximately 740 per month). Extra messages are priced at $0.05 each. The number of text messages and position reports are within the $45.00 minimum charge.

d. Pro-rata charge for dispatcher connection with the NMF is $2.00.

e. Total cost per month ranges from $138 for a terminal priced at current Geostar 2C levels to $69 for a mass produced $1000 terminal.

5. Qualcomm OmniTRACS

a. Amortized average equipment cost of $4100 equals $91.00 per month.

b. Monthly service and position reporting charge equals $35.00.

c. Cost per message is $0.05 per transmission plus $0.002 per character.

d. Monthly message charges range from $3.15 for one message per day to $15.75 for five messages per day.

e. Pro-rata charge for dispatcher connection with the NMF is $2.00.

f. Total cost per month ranges from $131 to $144.

6. <u>American Mobile Satellite Corporation (AMSC) Voice Service</u>[2]

a. Voice Services

a. Assumed $25 monthly service charge for access to the satellite system (similar in concept to monthly cellular access charges).

b. Amortized estimated high terminal price of $3500 equals $79 per month.

c. Amortized estimated low terminal price of $1500 equals $33 per month. This price will be associated with high production volumes.

d. Voice charges equal $0.83 per minute, or $2.49 per three-minute call.

e. For one-minute calls, the monthly charges range from $17.43 for one call per operating day to $87.15 for five calls per operating day.

f. Three-minute calls range from $52.29 to $261.45 for one and five calls per operating day.

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[2]The estimated equipment costs and service charges were taken from the 1987 and 1988 AMSC filings with the FCC. Since the AMSC system will not be operational until at least mid-1993, the reader should make some allowance for the uncertainty of estimated prices and inflation effects. For example, a 5% annual inflation rate compounded over six years equals a 34% increase in price levels (1.05^6). Using this inflation factor raises the estimated cost of the high price terminal to $4690, the forecast per-minute voice charge to $1.11, and cost per data packet to $0.027.

g. Total monthly costs for the $3500 terminal:

(1) One-minute calls: $121-$191.

(2) Three-minute calls: $156-$365.

h. Total monthly costs for the $1500 terminal:

(1) One-minute calls: $75-$145.

(2) Three-minute calls: $111-$320.

b. Data Services

a. Assumed $25 monthly service charge for access to the satellite system (similar in concept to monthly cellular access charges).

b. Amortized estimated high terminal price of $3500 equals $79 per month.

c. Amortized estimated low terminal price of $1500 equals $33 per month.

d. Messages charges are $0.02 per 256-bit packet (32 bytes). One packet is used for position reporting, and two packets are used per text or data message. Since position reports are not included in the base monthly fees, 12 packets or $0.24 per operating day are charged for positioning.

e. Monthly message charges range from $0.84 for one message per day to $4.20 for five messages per day. Position messages raise each of these costs by $5.04 per month.

f. Pro-rata charge for dispatcher connection with the network control center is $2.00.

g. Total cost per month for the $3500 terminal ranges from $111 to $115.

h. Total cost per month for the $1500 terminal ranges from $66 to $69.

7. <u>Meteor Burst</u>

a. Amortized $2000 equipment price equals $44.50.

b. Monthly service and position reporting charge is $35.00.

c. Message charge is $0.10 each. Monthly message charges range from $2.10 for one message per operating day to $10.50 for five messages per operating day.

d. Pro rata charge for dispatcher connection with the NMF is $2.00.

e. Total cost per month ranges from $84 for an average of one message per day to $92 for an average of five messages per day.

8. Cellular Radiotelephone

The Hellyer Communications rate structure is used for national and regional services [Ref. 23]. Local service charges are approximated from a survey of rates listed in the Official Cellular Roaming Handbook [Ref. 18].

a. Nationwide and Regional

a. Amortized $800 Hellyer equipment cost equals $17.80 per month.

b. $22.00 monthly service, plus $4.95 per month for follow-me roaming.

c. Roaming charge $2.00 per area per day. The number of roaming areas accessed is as follows:

Number of calls per day	1	2	3	4	5
Number of areas per day	1	2	2	3	3

d. Cellular roaming rate per minute is $0.60, or $1.80 per three-minute telephone call.

e. For one-minute calls, the monthly cellular phone charges range from $12.60 for one call per operating day to $63.00 for five calls per operating day. Long-distance connect charges range from $5.25 to $26.25 per month for one and five calls per operating day.

f. The monthly charge for three-minute cellular calls ranges from $37.80 for one phone call per operating day to $189.00 for five calls per operating day. Long-distance connect charges add $15.75 per month for one call per operating day to $78.75 per month for five calls per operating day.

g. For one-minute calls, the total cost per month varies between $105 and $260 for one to five calls per operating day.

h. For three-minute calls, the total cost per month varies between $140 and $439 for one to five calls per operating day.

b. Local

a. Amortized $800 Hellyer equipment cost equals $17.80 per month.

b. $22.00 monthly service.

c. Cellular phone call per minute is $0.40, or $1.20 per three-minute telephone call.

d. For one-minute calls, the monthly cellular phone charges range from $8.40 for one phone call per operating day to $42.00 for five calls per operating day.

e. For three-minute calls, the monthly cellular telephone charges range from $25.20 to $126.00 for one to five calls per operating day.

f. Total monthly costs for one minute calls vary between $48 and $82.

g. Total monthly costs for three-minute calls range from $65 to $166.

9. <u>Specialized Mobile Radio (SMR)</u>

The Motorola CoveragePLUS rate structure is used for nationwide and regional services.

a. Amortized Equipment and Operating Costs Common to All Configurations

a. Tier 1 terminal features include telephone interconnect and preset status messages. Amortized $1850 cost equals $41 per month.

b. Tier 2 terminal features include Tier 1 plus an alphanumeric keyboard and display terminal. Amortized $2950 cost equates to $66 per month.

c. Tier 3 terminal features include Tiers 1 and 2, plus an integrated Loran-C receiver. Amortized equipment charge of $3600 is $80 per month.

d. Monthly service charge is $35.00.

e. Pro rata charge for connection with the NMF is $8.00. This assumes a dedicated 4800 baud X.25 protocol leased line at $800 per month is required as per the marketing literature.

b. Nationwide and Regional <u>Data</u> Services

a. There is no additional charge for use of <u>preset</u> status messages.

b. Cost for up to 250 characters of freeform text and data is $0.05.

c. Total cost per month for one to five freeform messages per operating day ranges from:

(1) Tier 1: $85-$89.

(2) Tier 2: $110-$114.

(3) Tier 3: $124-$128.

c. Nationwide and Regional <u>Voice</u> Services

a. SMR voice roaming rate per minute is $0.50, or $1.50 per three-minute call. Monthly one-minute call charges range from $10.50 for one call per operating day to $52.50 for five calls per operating day. Three-minute monthly charges vary between $31.50 for one call per day to $157.50 for five calls per day.

b. One-minute monthly long-distance connect charges range from $5.25 for one call per operating day to $26.25 for five calls per operating day.

c. Three-minute long-distance connect charges range from $15.75 per month for one call per operating day to $78.75 per month for five calls per operating day.

d. Total costs per month:

	One minute	Three minute
Tier 1	$100 to $163	$131 to $320
Tier 2	$125 to $188	$156 to $344
Tier 3	$139 to $202	$170 to $359

d. Nationwide and Regional Mixed Services

a. Same freeform text/data and voice costs per communication as above. Costs for combined service are calculated in the following matrix:

Number of Data Transmissions[3]	4	3	2	1
Number of Voice Transmissions	1	2	3	4
One Minute Monthly Cost ($)	16	31	47	62
Three Minute Monthly Cost ($)	47	93	140	186

b. Total cost per month ranges from:

	One Minute	Three Minutes
Tier 1	$84 to $146	$84 to $270
Tier 2	$114 to $179	$114 to $296
Tier 3	$128 to $186	$128 to $310

e. Local

a. Voice dispatch, no connection with the telephone system.

b. $900 cost of mobile radio amortized is $20.00.

c. Monthly service is $15.00.

d. Total cost per month is $35.

10. Mobile Data Systems

Costs for ARDIS nationwide mobile data terminals and services were not available at the time this thesis was written. Accordingly, the Motorola Digital Radio Network cost structure is used for nationwide, regional, and local area coverage.

a. Amortized $3500 terminal equals $77.86 per month.

b. Amortized $1600 terminal equals $35.59 per month.

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[3]Tier One uses preset status messages for which there are no additional user charges.

c. $30.00 monthly service charge.

d. Pro-rata charge for dispatcher connection with the NMF is $2.00.

e. Message charge is $0.10 per 240 or less characters (peak-hour rate between 7 a.m. and 6 p.m.). Monthly message charges range from $2.10 for one message per operating day to $10.50 for five messages per operating day.

f. For the higher-priced terminal, total cost per month ranges from $112 for one message per operating day to $121 for five messages per operating day.

g. For the lower-priced terminal, total cost per month ranges from $70 for one message per operating day to $79 for five messages per operating day.

11. Paging

a. Nationwide and Regional

(1) Alphanumeric Paging.

a. Charge for rental and service is $60.00.

b. Inbound long-distance charges for communication between the driver and dispatcher are reduced by 50%.

c. For one-minute calls, the telephone charges for one to five calls per operating day range from approximately $3 to $13 per month. Total monthly communication costs vary between $63 and $73.

d. For three-minute calls, the telephone charges for one to five calls per operating day range from approximately $8 to $39 per month. Total costs vary between $68 and $99 per month.

b. Local

(1) Numeric Paging.

a. $150 cost of pager amortized is $4 per month.

b. Monthly service is $15.00 per month.

c. Local phone charges are reduced by 50%, and range from $2.25 to $13.25 per month.

d. Fully-allocated costs vary between \$21 and \$32 per month.

13. Cost Summary

The fully-allocated costs described above are listed in Table 2. Selected items are graphed in Figures 32 through 38. Voice communication times are indicated in the graph legends.

D. USER COST ANALYSIS

These fully-allocated costs are based on a limited range of product and price data. The market for all of these services is continually evolving. Different prices will undoubtedly be charged by equipment vendors and service providers as the market becomes more defined, the technologies are refined and adopted, and production volume efficiencies occur. However, these existing price levels serve as a benchmark for comparison and analysis.

1. Comparison with the Public Telephone System Benchmark

The total monthly communication cost of all alternative systems exceeds the cost of using the public telephone system. This difference can be thought of as a representation of the increased profit, operating efficiency, expense reduction, or combination of these elements which must be achieved to recover the difference in cost.

2. Fixed, Semi-variable, and Variable Communication Costs

Systems with fixed communications expenses (amortized equipment cost plus monthly access fee) do not change in total

TABLE 2

NATIONWIDE AND REGIONAL MOBILE COMMUNICATION SYSTEM COST MODEL SUMMARY

COMMUNICATION SYSTEM	FIXED COST PER MONTH	VARIABLE COST PER MESSAGE	TOTAL MONTHLY COST FOR COMMUNICATIONS PER OPERATING DAY ($ ROUNDED)				
			1	2	3	4	5
AT&T:							
1 Minute Call	N/A	$5.25	$5	$11	$16	$21	$26
3 Minute Call	N/A	15.75	16	32	47	63	79
Geostar:							
Geostar 2.0 & AT&T 1 Minute Call	$122	$2.63	$125	$128	$130	$133	$135
Geostar 2.0 & AT&T 3 Minute Call	122	7.88	130	138	146	153	161
Geostar 2.0 & Nationwide Pager	182	N/A *	182	182	182	182	182
Geostar 2C	138	N/A *	138	138	138	138	138
Geostar 3.0 - High Cost Terminal	138	N/A *	138	138	138	138	138
Geostar 3.0 - Low Cost Terminal	69	N/A *	69	69	69	69	69

TABLE 2 (CONTINUED)

COMMUNICATION SYSTEM	FIXED COST PER MONTH	VARIABLE COST PER MESSAGE	TOTAL MONTHLY COST FOR COMMUNICATIONS PER OPERATING DAY ($ ROUNDED)				
QUALCOMM OmniTRACS	$128	$3.15	$131	$134	$138	$141	$144
American Mobile Satellite Corporation (**):							
Voice Services:							
High Cost Terminal & 1 Minute Call	$104	$17.43	$121	$139	$156	$174	$191
Low Cost Terminal & 1 Minute Call	58	17.43	75	93	110	128	145
High Cost Terminal & 3 Minute Call	104	52.29	156	209	261	313	365
Low Cost Terminal & 3 Minute Call	58	52.29	110	163	215	267	319
Text and Data Services:							
High Cost Terminal	111	0.84	112	113	114	114	115
Low Cost Terminal	65	0.84	66	67	68	68	69
Meteor Burst (Pegasus)	$82	$2.10	$84	$86	$88	$90	$92

* Total number of communications per day is within the minimum monthly charge.

** These cost figures do not take inflation into account. See the footnote in the AMSC section of the text.

TABLE 2 (CONTINUED)

COMMUNICATION SYSTEM	FIXED COST PER MONTH	VARIABLE COST PER MESSAGE	TOTAL MONTHLY COST FOR COMMUNICATIONS PER OPERATING DAY ($ ROUNDED)				
			1	2	3	4	5
Motorola CoveragePLUS SMR:							
Tier 1 - Preset Status Messages	$84	$0	$84	$84	$84	$84	$84
Tier 2 - Preset Status Messages	109	0	109	109	109	109	109
Tier 3 - Preset Status Messages	123	0	123	123	123	123	123
Tier 2 - Freeform Text and Data	109	1.05	110	111	112	113	114
Tier 3 - Freeform Text and Data	123	1.05	124	125	126	127	128
Tier 1 - 1 Minute Voice	$84	$15.75	$100	$116	$132	$147	$163
Tier 2 - 1 Minute Voice	109	15.75	125	141	157	172	188
Tier 3 - 1 Minute Voice	123	15.75	139	155	171	186	202
Tier 1 - 3 Minute Voice	84.00	47.26	131	178	226	273	320
Tier 2 - 3 Minute Voice	109	47.26	156	203	251	298	344
Tier 3 - 3 Minute Voice	123	47.26	170	217	265	312	359
		# Voice (# Data)	0(5)	1(4)	2(3)	3(2)	4(1)
Tier 1 - Mixed Preset Data & 1 Minute Voice	$84	See Text	$84	$100	$115	$131	$146
Tier 2 - Mixed Freeform Data & 1 Minute Voice	109	See Text	114	129	143	158	173
Tier 3 - Mixed Freeform Data & 1 Minute Voice	123	See Text	128	143	157	172	186
Tier 1 - Mixed Preset Data & 3 Minute Voice	$84	See Text	84	131	177	224	270
Tier 2 - Mixed Freeform Data & 3 Minute Voice	109	See Text	114	160	205	251	296
Tier 3 - Mixed Freeform Data & 3 Minute Voice	123	See Text	128	173	219	265	310

TABLE 2 (CONTINUED)

COMMUNICATION SYSTEM	FIXED COST PER MONTH	VARIABLE COST PER MESSAGE	TOTAL MONTHLY COST FOR COMMUNICATIONS PER OPERATING DAY ($ ROUNDED)				
			1	2	3	4	5
Hellyer Cellular:							
1 Minute Call	$45	See Text	$105	$165	$183	$243	$260
3 Minute Call	45	See Text	140	236	289	385	439
Motorola Data Radio Network:							
High Priced Terminal	$110	$2.10	$112	$114	$117	$119	$121
Low Priced Terminal	68	2.10	70	72	75	77	79
Nationwide Paging:							
1 Minute Call	$60	$2.63	$63	$66	$68	$71	$73
3 Minute Call	60	7.88	68	76	84	91	99

TABLE 2 (CONTINUED)

COMMUNICATION SYSTEM	FIXED COST PER MONTH	VARIABLE COST PER MESSAGE	TOTAL MONTHLY COST FOR COMMUNICATIONS PER OPERATING DAY ($ ROUNDED)				
			1	2	3	4	5
Local Telephone	N/A	$5.25	$5	$11	$16	$21	$26
Local SMR Voice Dispatch	$35	N/A	$35	$35	$35	$35	$35
Local Cellular:							
1 Minute Call	$40	$8.40	$48	$57	$65	$74	$82
3 Minute Call	40	25.2	65	90	116	141	166
Motorola Data Radio Network:							
High Priced Terminal	$110	$2.10	$112	$114	$117	$119	$121
Low Priced Terminal	68	2.10	70	72	75	77	79
Local Numeric Paging	$19	$2.25	$21	$23	$26	$28	$32

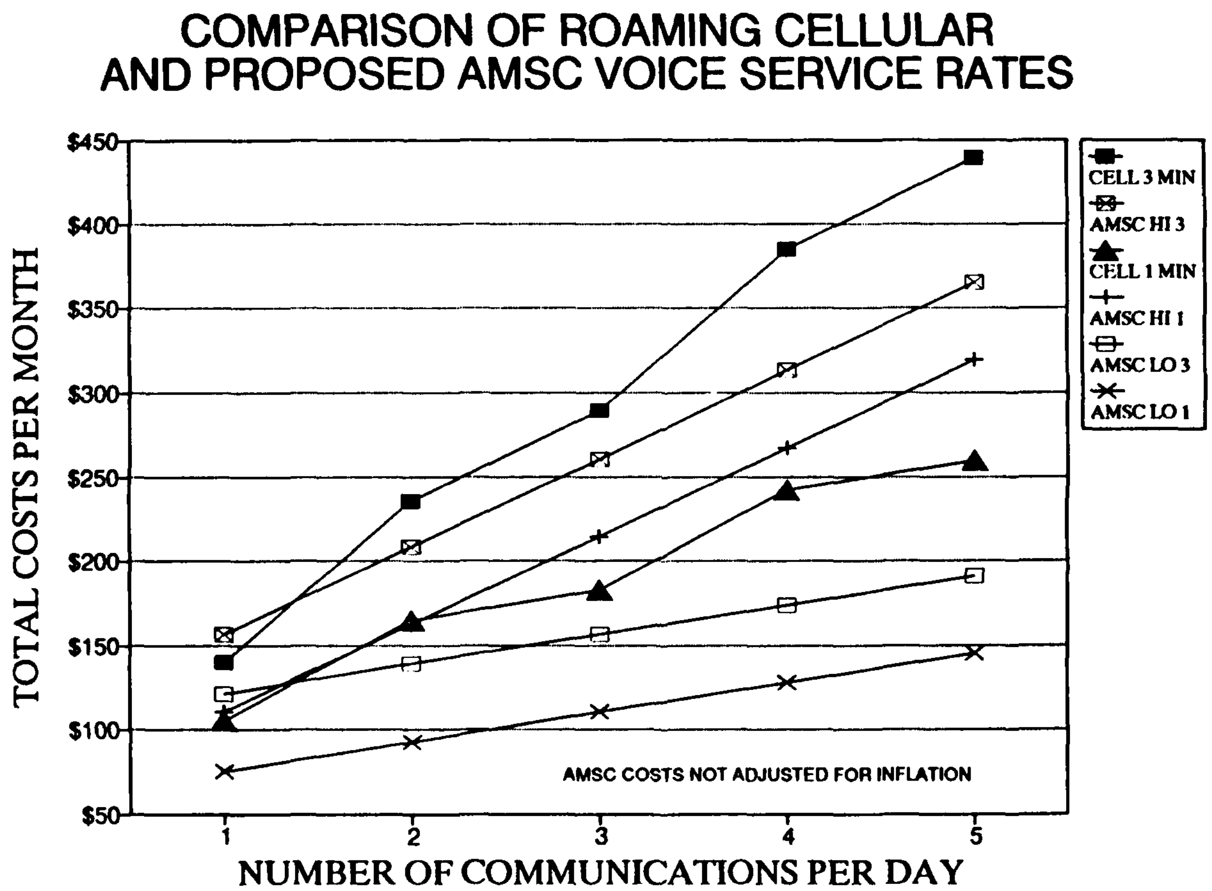

Figure 32. Comparison of Roaming Cellular and Proposed AMSC Voice Service Rates

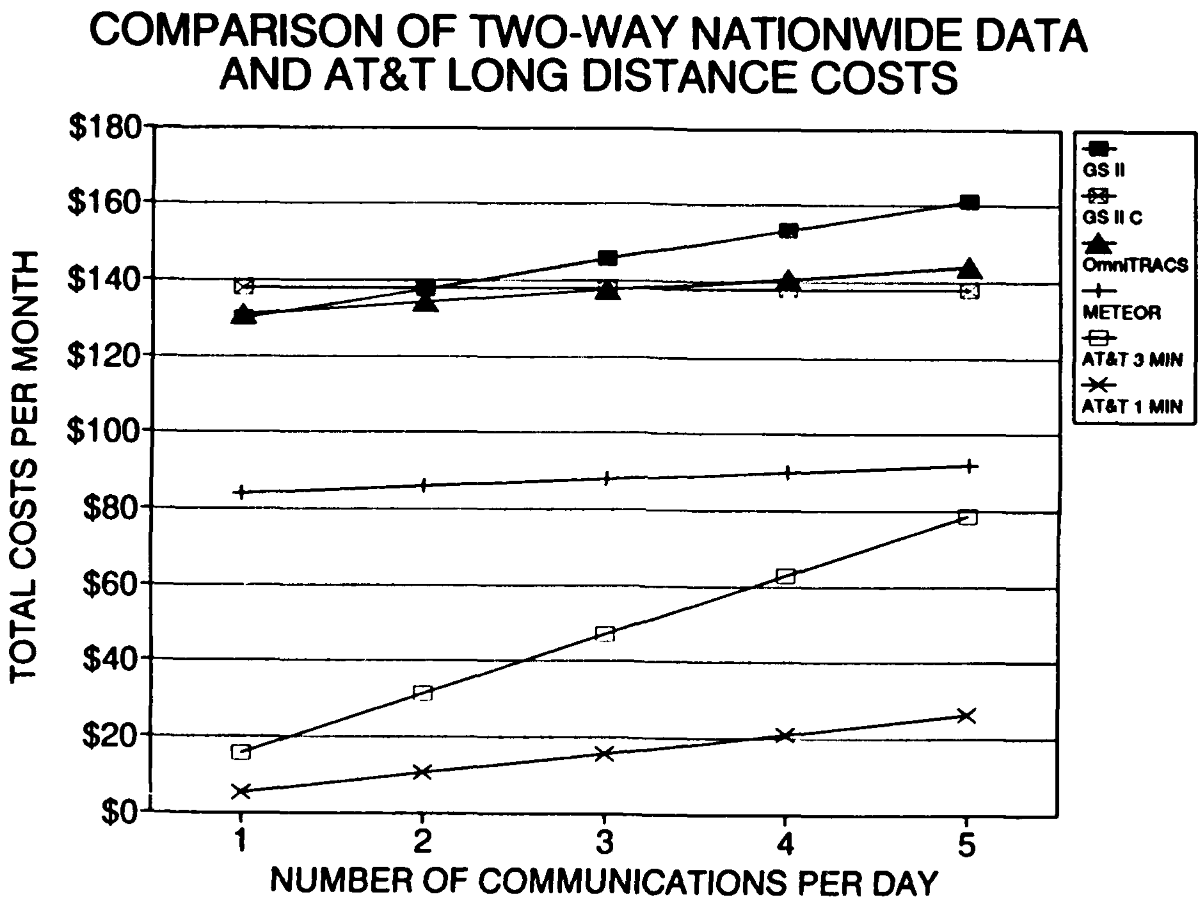

Figure 33. Comparison of Two-Way Nationwide Data and AT&T Long-Distance Costs

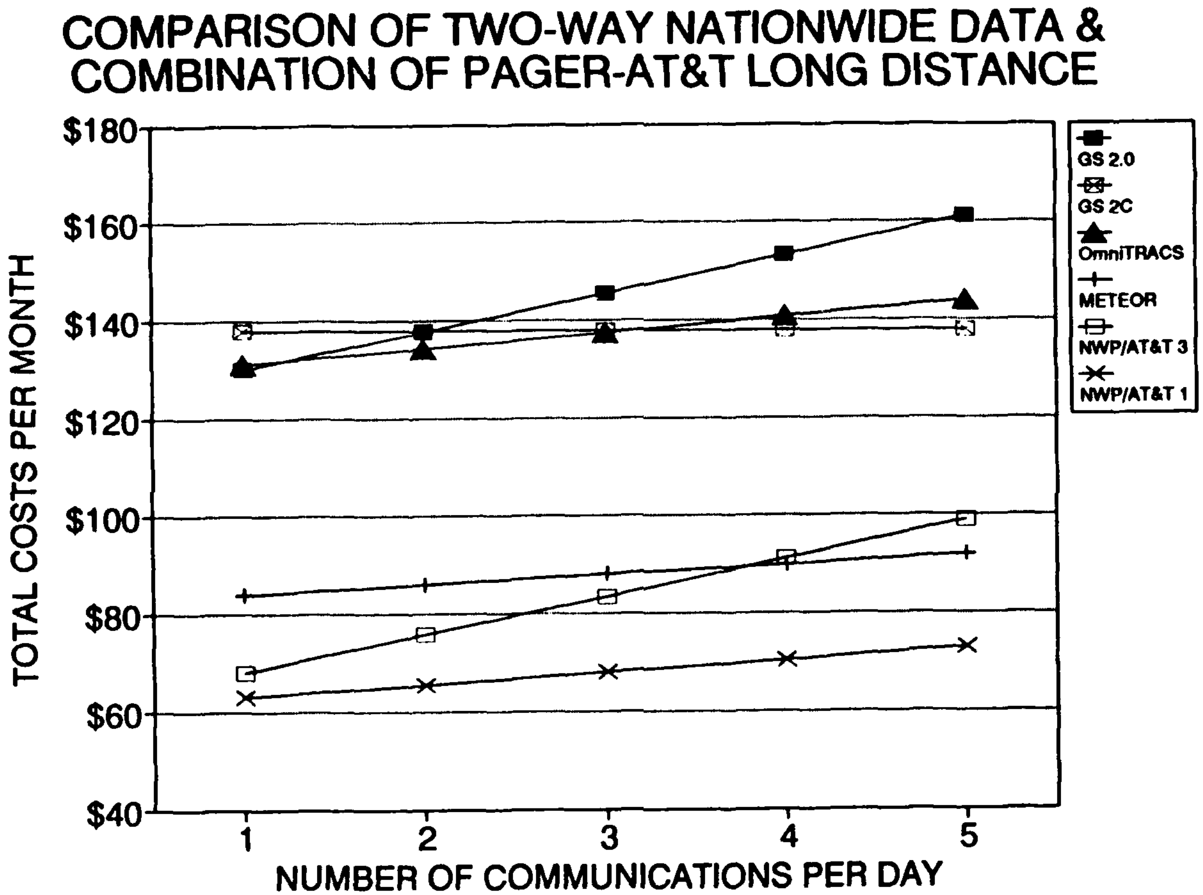

Figure 34. Comparison of Two-Way Nationwide Data and Combination of Pager-AT&T Long Distance

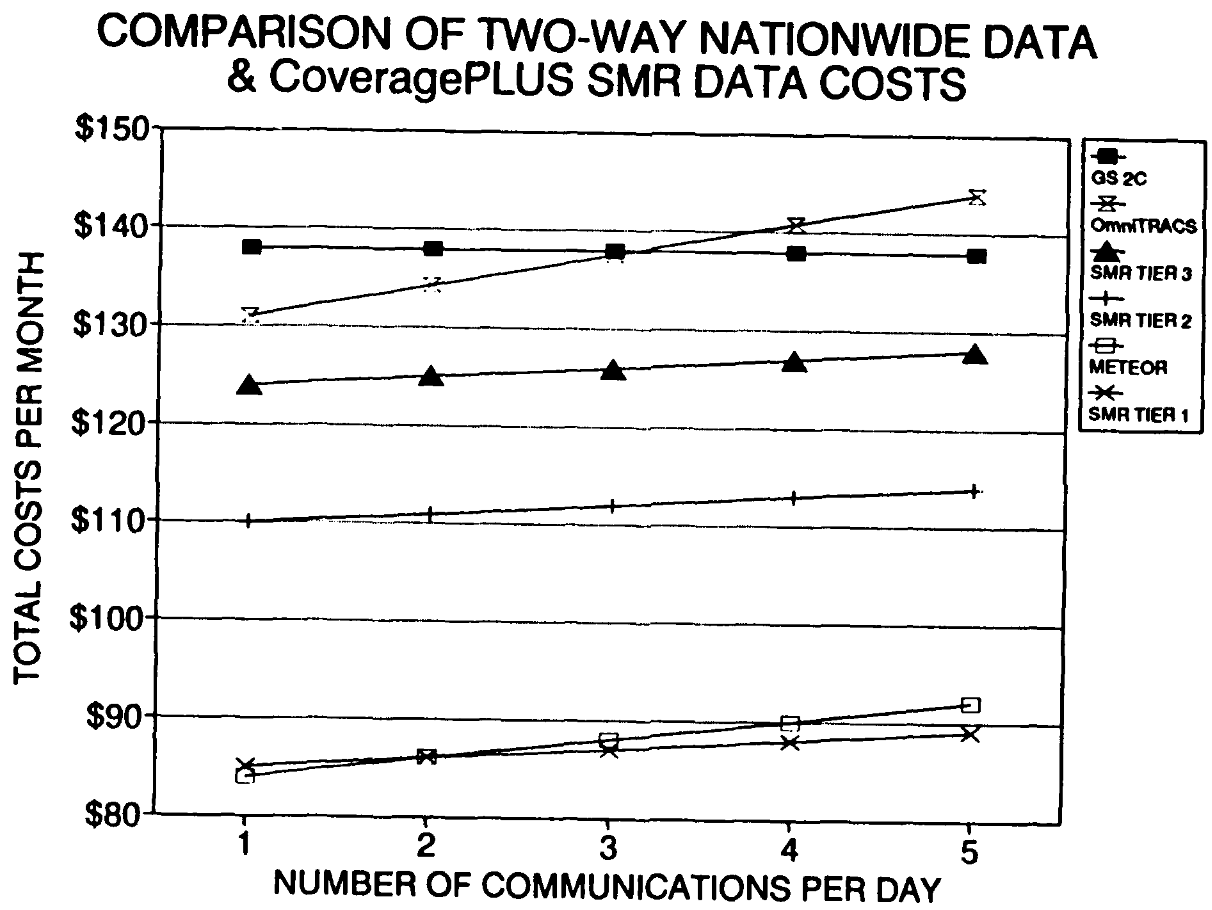

Figure 35. Comparison of Two-Way Nationwide Data and CoveragePLUS SMR Data Costs

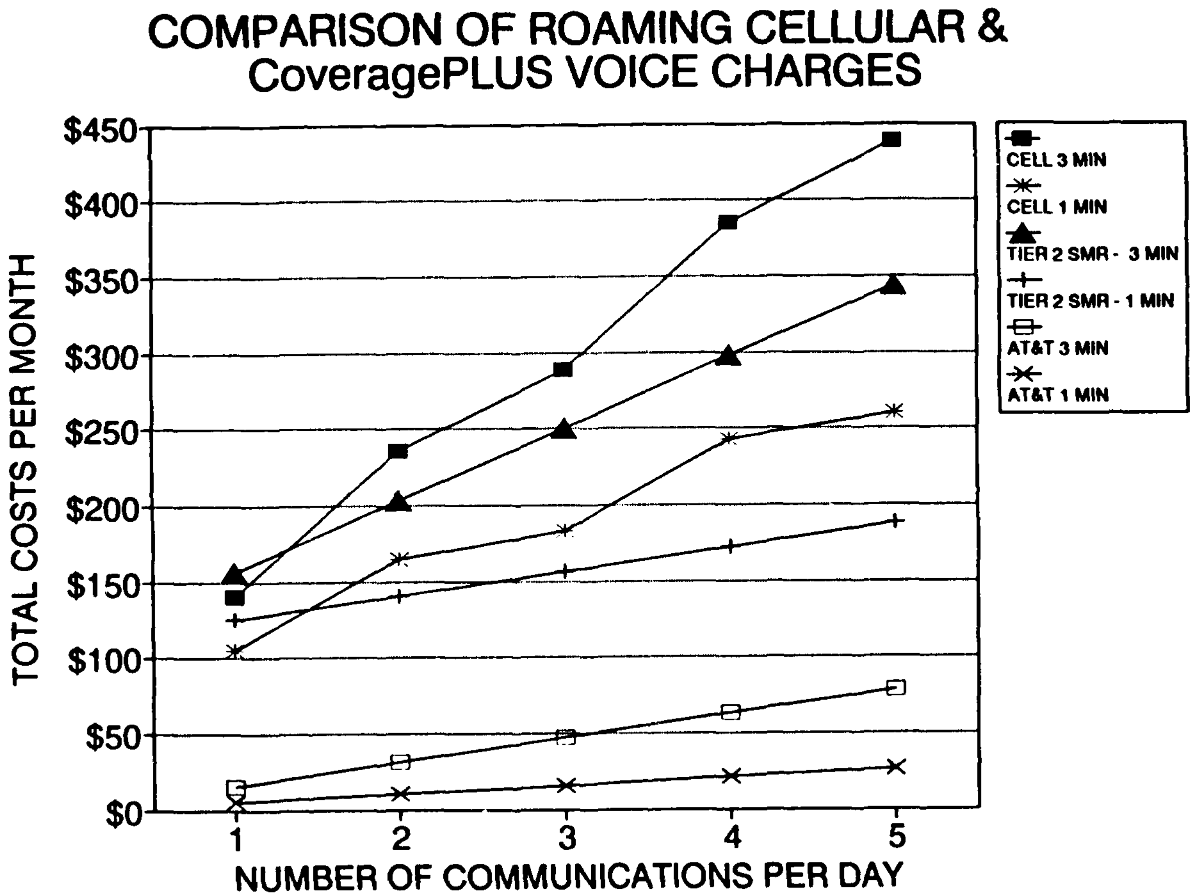

Figure 36. Comparison of Roaming Cellular and CoveragePLUS Voice Charges

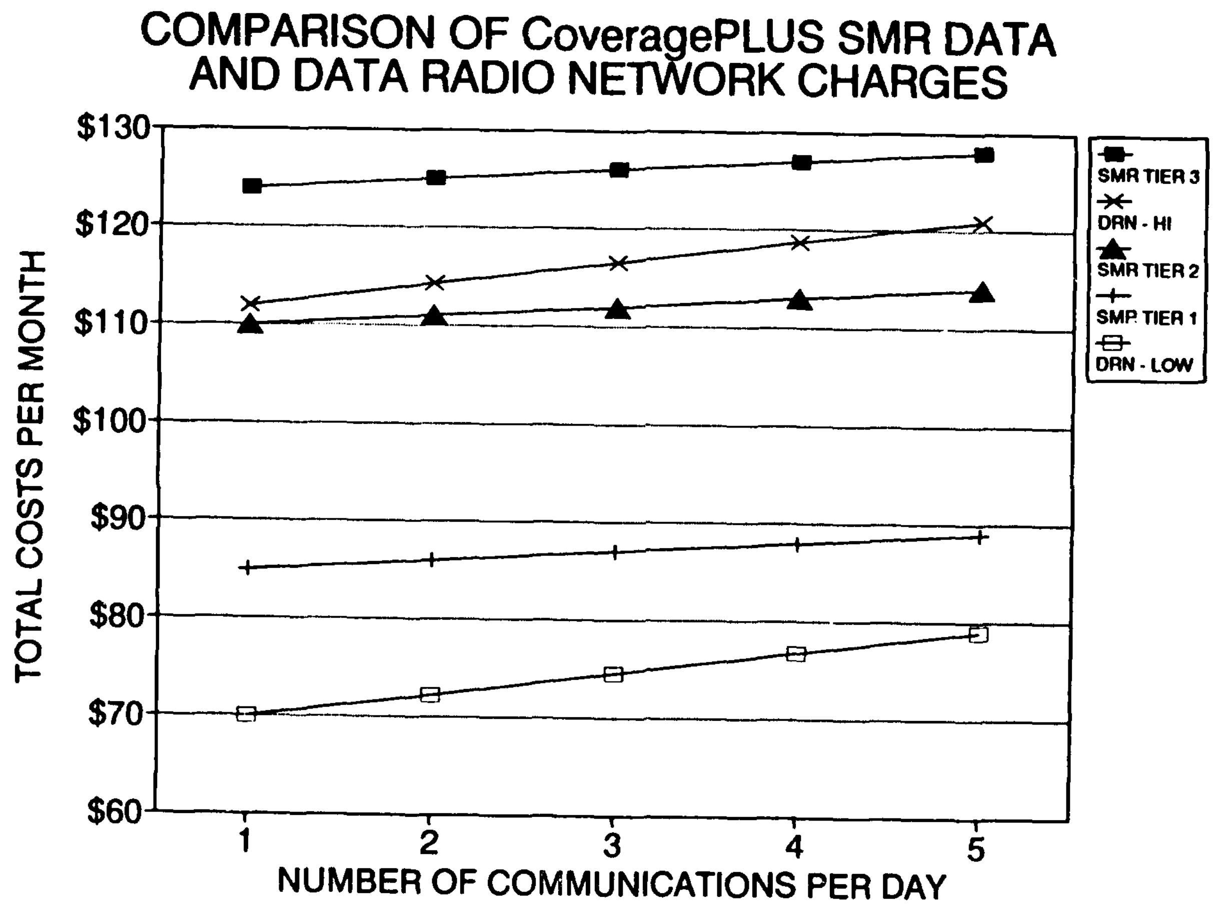

Figure 37. Comparison of CoveragePLUS SMR Data and Data Radio Network Charges

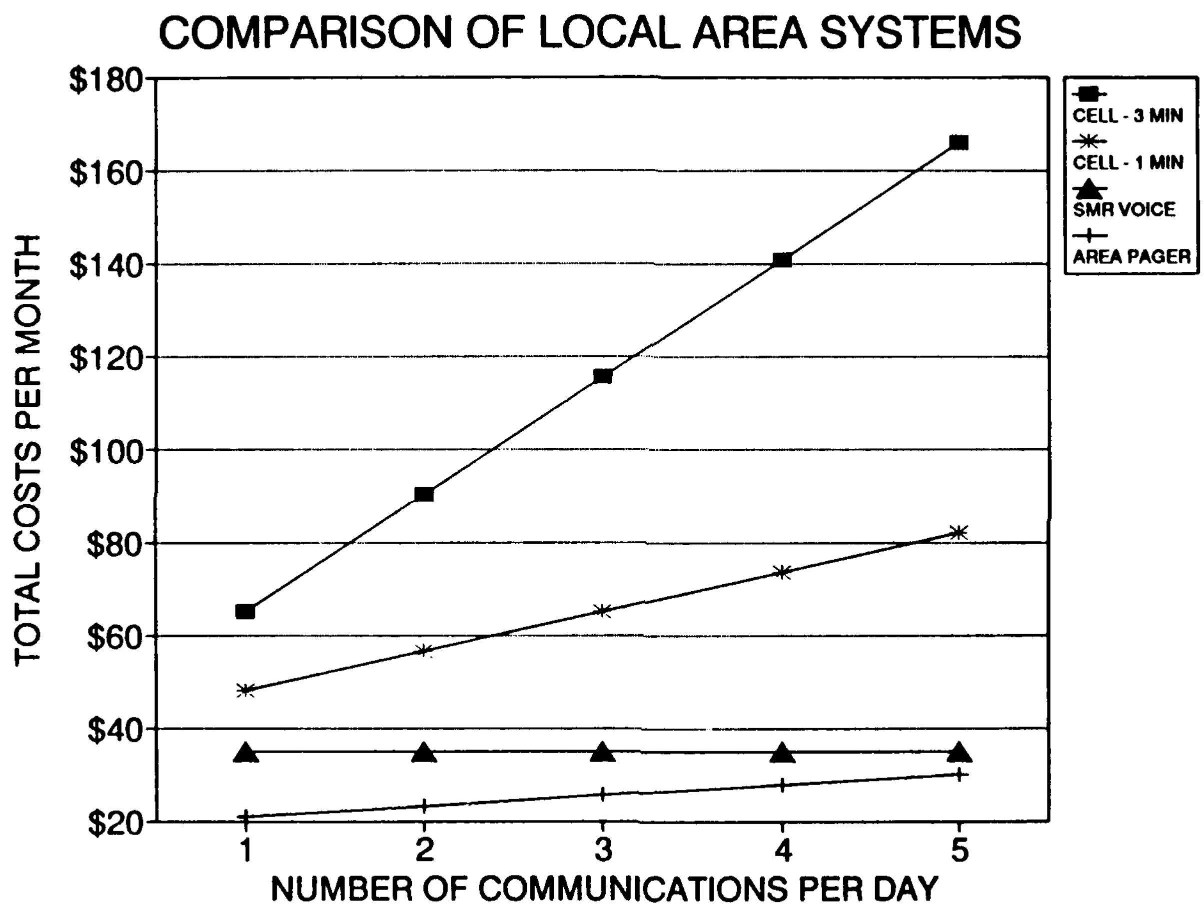

Figure 38. Comparison of Local Area Systems

price regardless of the volume of use. Systems with semi-variable total costs (fixed amortization and monthly access, variable message or connect charges) vary in total cost based on amount of use. With both these systems the average communication cost per message declines with an increase in the quantity or duration of communication. This is because the fixed equipment and service expenses are being spread out over a greater number or length of transmissions. Systems which to the user are only variable in cost, such as the public telephone system, vary in direct proportion to the amount of use. Assuming the rate structure does not change with calling volume, the variable cost per minute will always be the same.

Alternative systems which are only used one or two times per operating day are much more expensive on a per-call basis than the public telephone system. At this level of use the benefits of using a mobile communication system must be correspondingly greater to overcome the difference in cost.

Average costs per communication are reflected in Table 3 and graphed in Figures 39 through 45.

3. Voice and Digital Services

It is readily apparent from the rate structures that mobile voice is more expensive than mobile data. This reflects the fact that voice is electronically less efficient for conveying information. When comparing communication modes, a greater number of channels, bandwidth and time are

TABLE 3

NATIONWIDE AND REGIONAL MOBILE COMMUNICATION SYSTEM COST MODEL SUMMARY

COMMUNICATION SYSTEM	AVERAGE COST PER COMMUNICATION				
	COMMUNICATIONS PER OPERATING DAY				
	1	2	3	4	5
AT&T:					
AT&T - 1 Minute Call	$0.25	$0.25	$0.25	$0.25	$0.25
AT&T - 3 Minute Call	0.75	0.75	0.75	0.75	0.75
Geostar:					
Geostar 2.0 & AT&T 1 Minute Call	$5.95	$3.04	$2.06	$1.58	$1.29
Geostar 2.0 & AT&T 3 Minute Call	6.19	3.28	2.31	1.82	1.53
Geostar 2.0 & Nationwide Pager	8.67	4.33	2.89	2.17	1.73
Geostar 2C	6.57	3.29	2.19	1.64	1.31
Geostar 3.0 - High Cost Terminal	6.57	3.29	2.19	1.64	1.31
Geostar 3.0 - Low Cost Terminal	3.29	1.64	1.10	0.82	0.66

TABLE 3 (CONTINUED)

COMMUNICATION SYSTEM	AVERAGE COST PER COMMUNICATION COMMUNICATIONS PER OPERATING DAY				
	1	2	3	4	5
QUALCOMM OmniTRACS	$6.24	$3.20	$2.18	$1.68	$1.37
American Mobile Satellite Consortium: *					
Voice Services:					
High Cost Terminal & 1 Minute Call	$5.78	$3.31	$2.48	$2.07	$1.82
Low Cost Terminal & 1 Minute Call	3.59	2.21	1.75	1.52	1.38
High Cost Terminal & 3 Minute Call	7.44	4.97	4.14	3.73	3.48
Low Cost Terminal & 3 Minute Call	5.25	3.87	3.41	3.18	3.04
Data Services:					
High Cost Terminal	$5.33	$2.68	$1.80	$1.36	$1.10
Low Cost Terminal	3.14	1.59	1.07	0.81	0.66
Meteor Burst (Pegasus)	$4.00	$2.05	$1.40	$1.07	$0.88

* These cost figures do not take inflation into account. See the footnote in the AMSC section of the text.

TABLE 3 (CONTINUED)

AVERAGE COST PER COMMUNICATION

COMMUNICATIONS PER OPERATING DAY

	1	2	3	4	5
Motorola CoveragePLUS SMR:					
Tier 1 - Preset Status Messages	$4.00	$2.00	$1.33	$1.00	$0.80
Tier 2 - Preset Status Messages	5.19	2.60	1.73	1.30	1.04
Tier 3 - Preset Status Messages	5.86	2.93	1.95	1.46	1.17
Tier 1 - Preset Status Messages	4.00	2.00	1.33	1.00	0.80
Tier 2 - Freeform Text and Data	5.24	2.64	1.78	1.35	1.09
Tier 3 - Freeform Text and Data	5.90	2.98	2.00	1.51	1.22
Tier 1 - 1 Minute Voice	$4.76	$2.76	$2.09	$1.75	$1.55
Tier 2 - 1 Minute Voice	5.95	3.35	2.48	2.05	1.79
Tier 3 - 1 Minute Voice	6.62	3.68	2.71	2.22	1.92
Tier 1 - 3 Minute Voice	6.24	4.24	3.58	3.25	3.05
Tier 2 - 3 Minute Voice	7.43	4.83	3.97	3.54	3.28
Tier 3 - 3 Minute Voice	8.10	5.17	4.20	3.71	3.42
# Voice (# Data) *	0(5)	1(4)	2(3)	3(2)	4(1)
Tier 1 - Mixed Preset Data & 1 Min. Call	$4.00	$2.38	$1.83	$1.56	$1.39
Tier 2 - Mixed Freeform Data & 1 Min. Call	5.43	3.07	2.27	1.88	1.65
Tier 3 - Mixed Freeform Data & 1 Min. Call	6.10	3.40	2.49	2.05	1.77
Tier 1 - Mixed Preset Data & 3 Min. Call	4.00	3.12	2.81	2.67	2.57
Tier 2 - Mixed Freeform Data & 3 Min. Call	5.43	3.81	3.25	2.99	2.82
Tier 3 - Mixed Freeform Data & 3 Min. Call	6.10	4.12	3.48	3.15	2.95

* See Text

TABLE 3 (CONTINUED)

COMMUNICATION SYSTEM	AVERAGE COST PER COMMUNICATION				
	COMMUNICATIONS PER OPERATING DAY				
Hellyer Cellular:	1	2	3	4	5
1 Minute Call	$5.00	$3.93	$2.90	$2.89	$2.48
3 Minute Call	6.67	5.61	4.59	4.58	4.18
Motorola Data Radio Network:					
High Priced Terminal	$5.33	$2.72	$1.85	$1.41	$1.15
Low Priced Terminal	3.33	1.72	1.18	0.91	0.75
Nationwide Paging:					
1 Minute Call	$3.00	$1.56	$1.08	$0.84	$0.70
3 Minute Call	3.24	1.80	1.33	1.09	0.94

TABLE 3 (CONTINUED)

COMMUNICATION SYSTEM	AVERAGE COST PER COMMUNICATION				
	COMMUNICATIONS PER OPERATING DAY				
	1	2	3	4	5
Local Telephone	$0.25	$0.25	$0.25	$0.25	$0.25
Local SMR Voice Dispatch	$1.67	$0.83	$0.56	$0.42	$0.33
Local Cellular:					
1 Minute Call	$2.29	$1.35	$1.03	$0.88	$0.78
3 Minute Call	3.10	2.15	1.83	1.68	1.58
Motorola Data Radio Network:					
High Priced Terminal	$5.33	$2.72	$1.85	$1.41	$1.15
Low Priced Terminal	3.33	1.72	1.18	0.91	0.75
Local Numeric Paging	$1.00	$0.57	$0.42	$0.35	$0.30

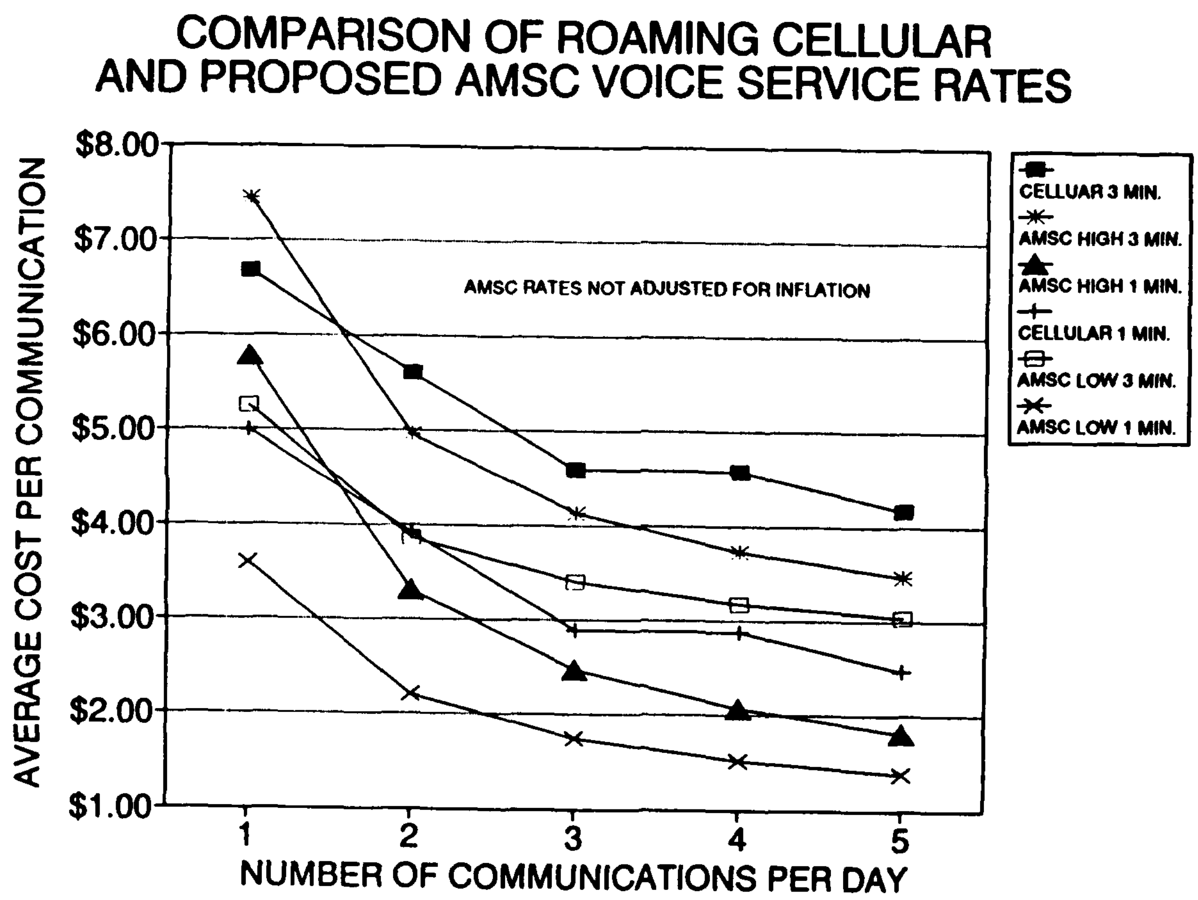

Figure 39. Comparison of Roaming Cellular and Proposed AMSC Voice Service Rates

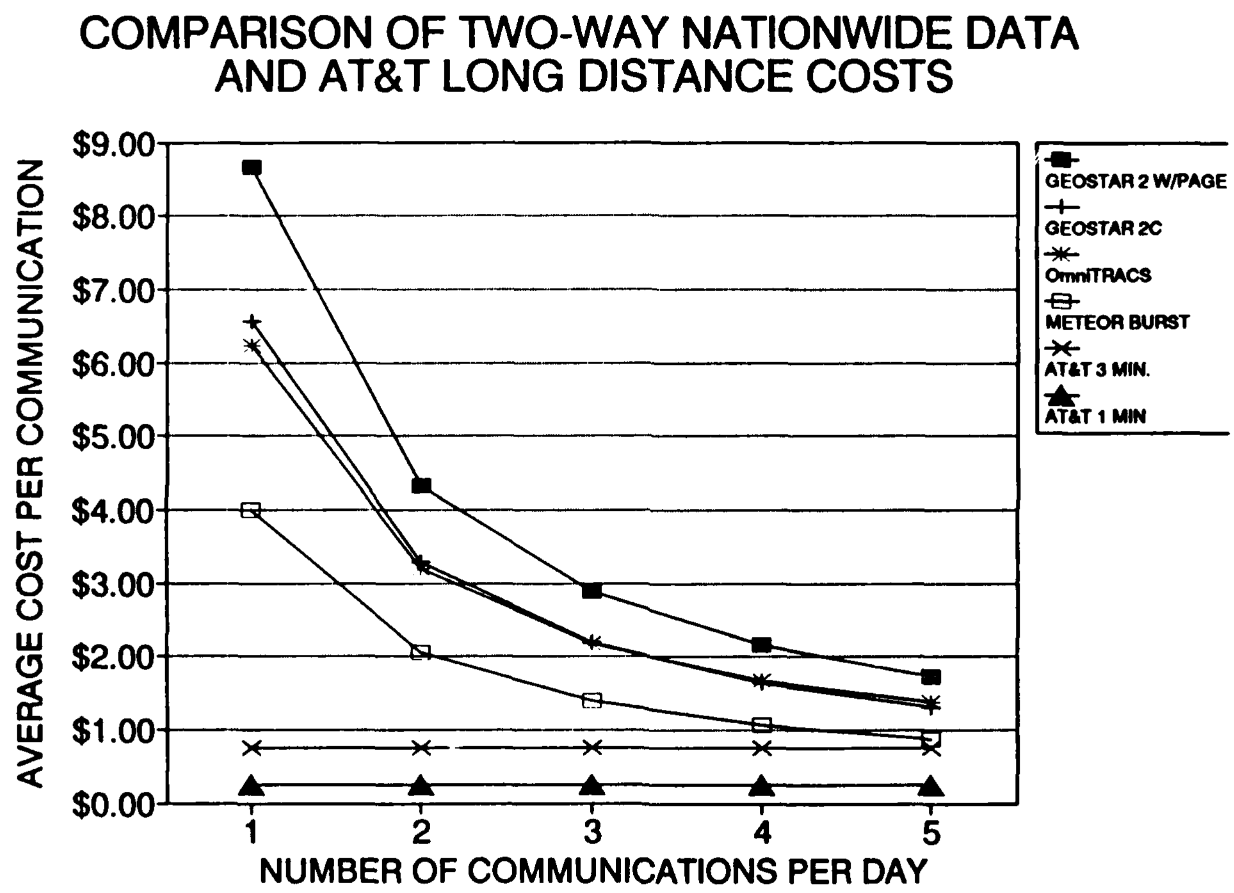

Figure 40. Comparison of Two-Way Nationwide Data and AT&T Long-Distance Costs

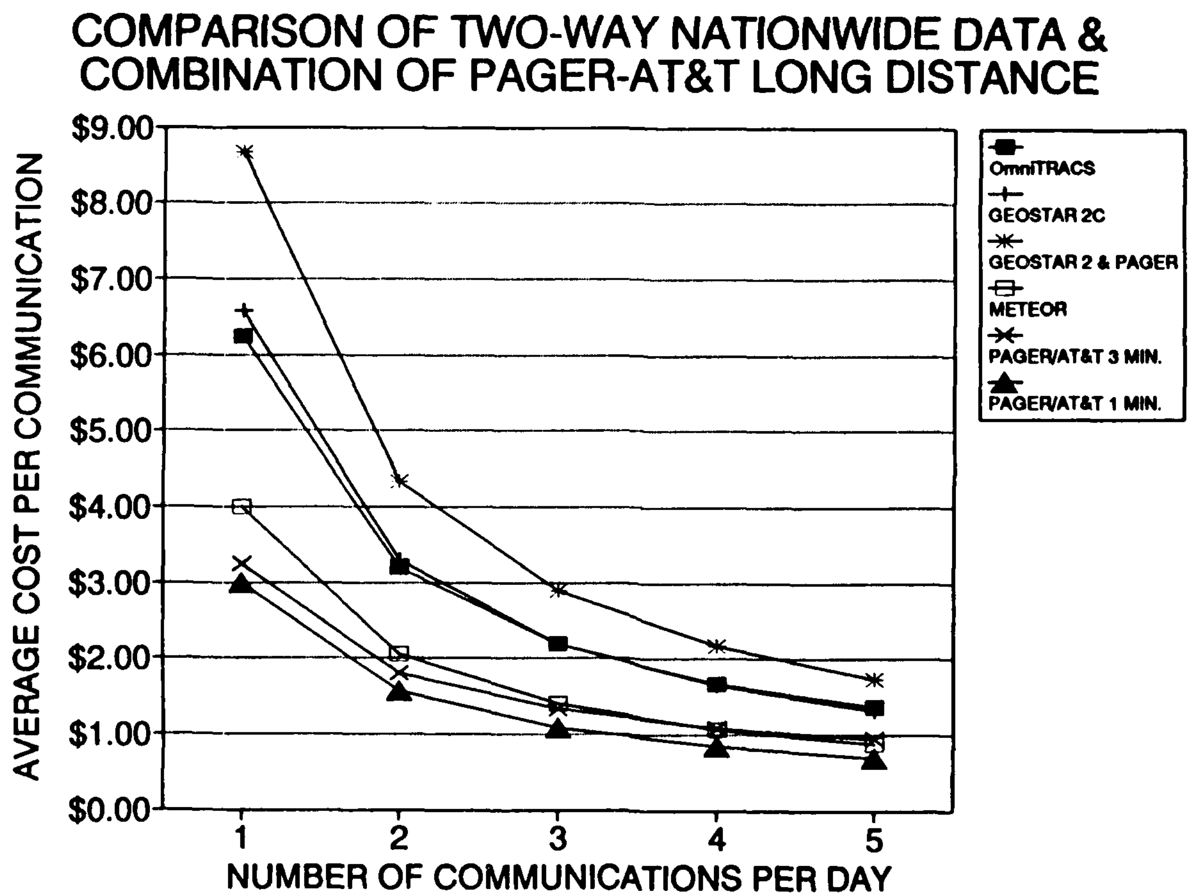

Figure 41. Comparison of Two-Way Nationwide Data and Combination of Pager-AT&T Long Distance

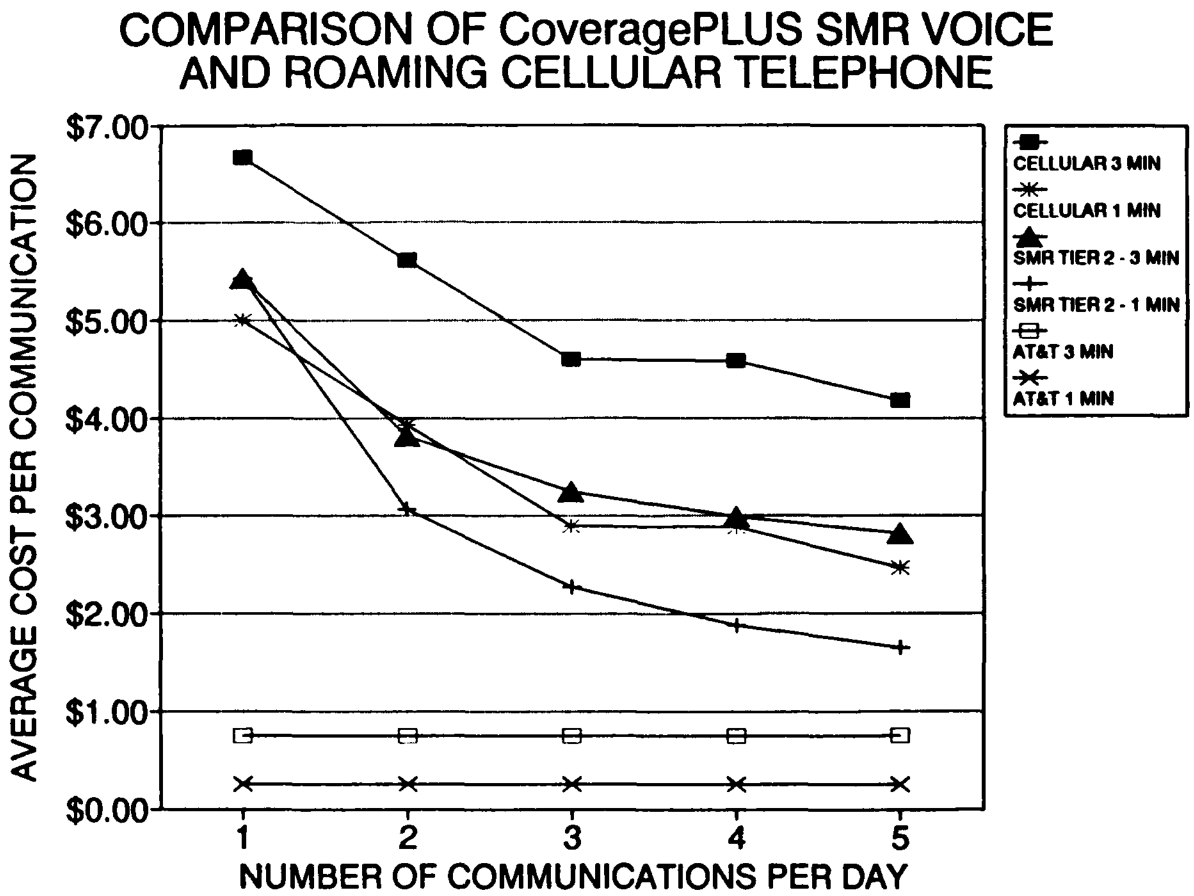

Figure 42. Comparison of CoveragePLUS SMR Voice and Roaming Cellular Telephone

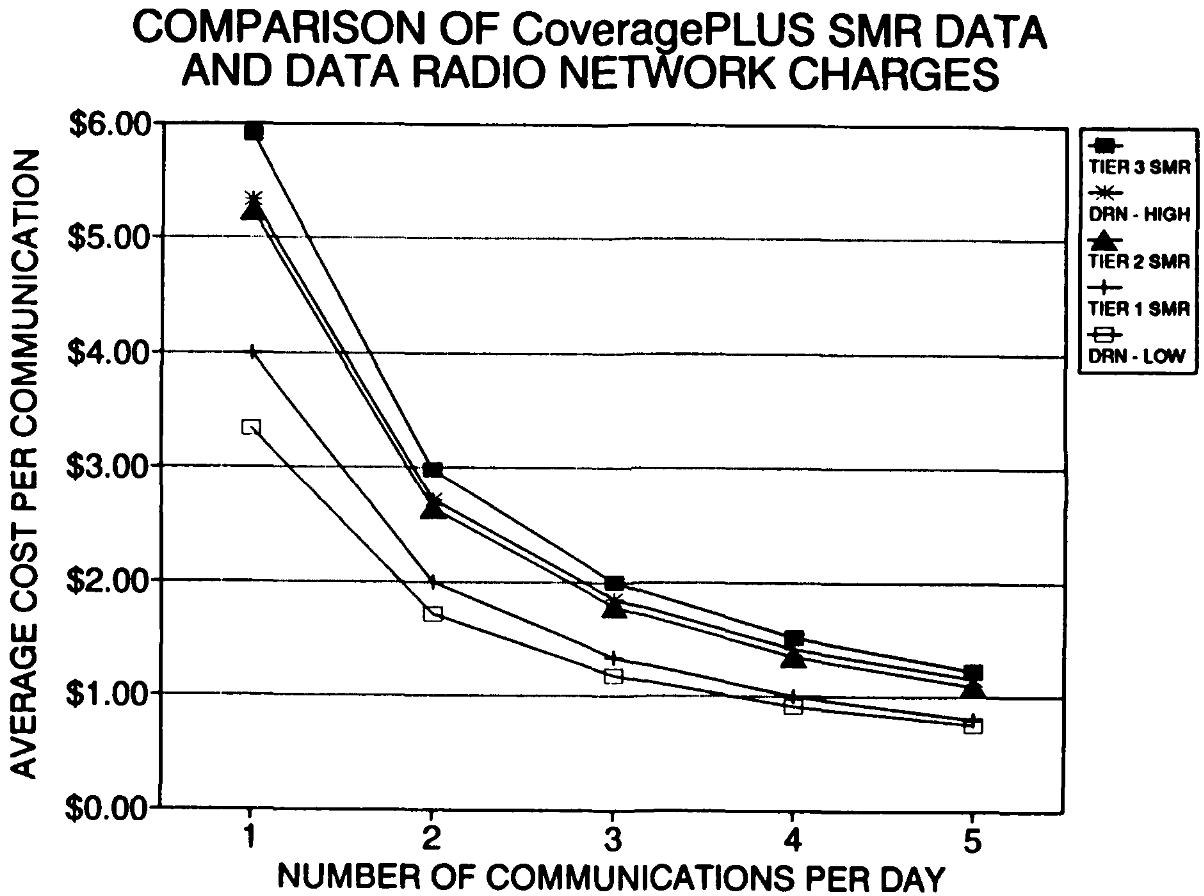

Figure 43. Comparison of CoveragePLUS SMR Data and Data Radio Network Charges

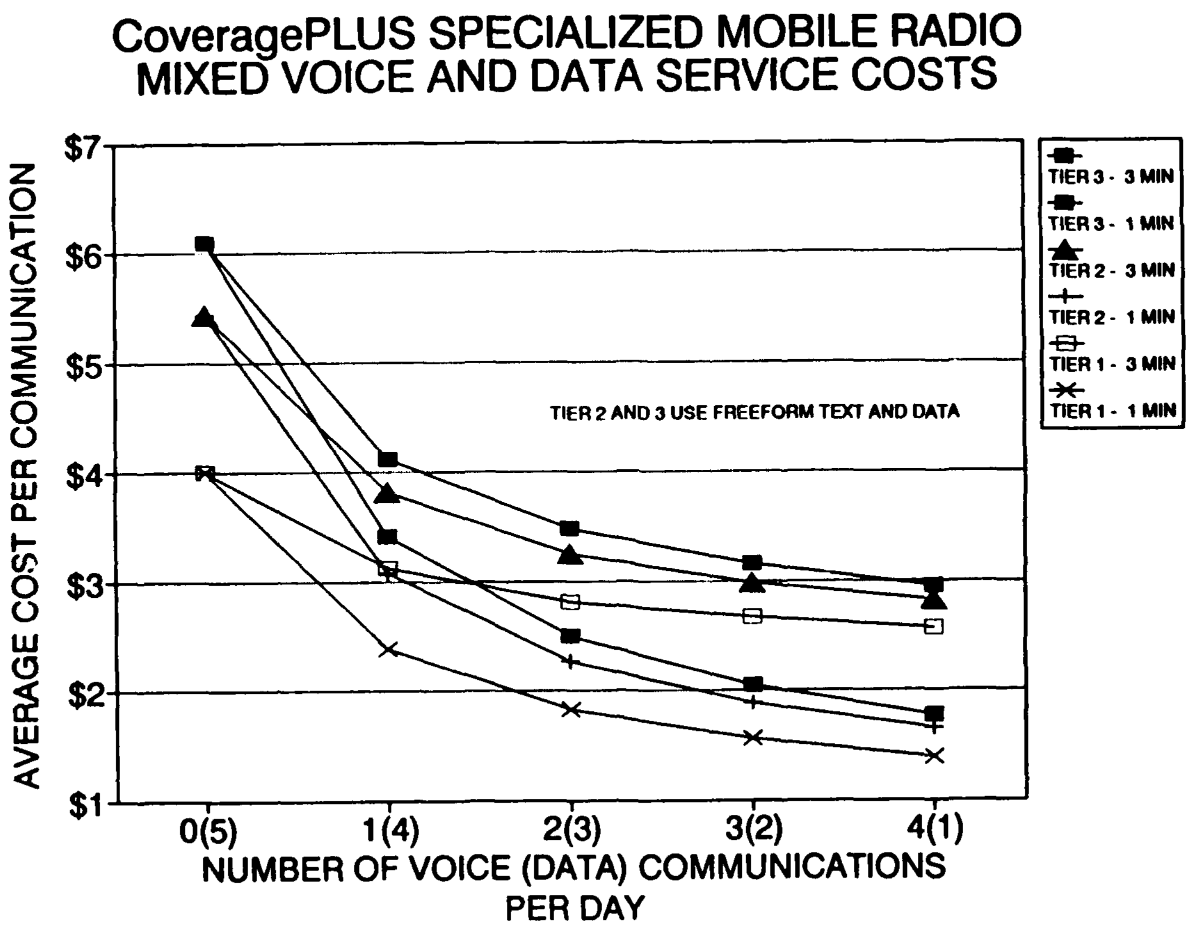

Figure 44. CoveragePLUS Specialized Mobile Radio Mixed Voice and Data Service Costs

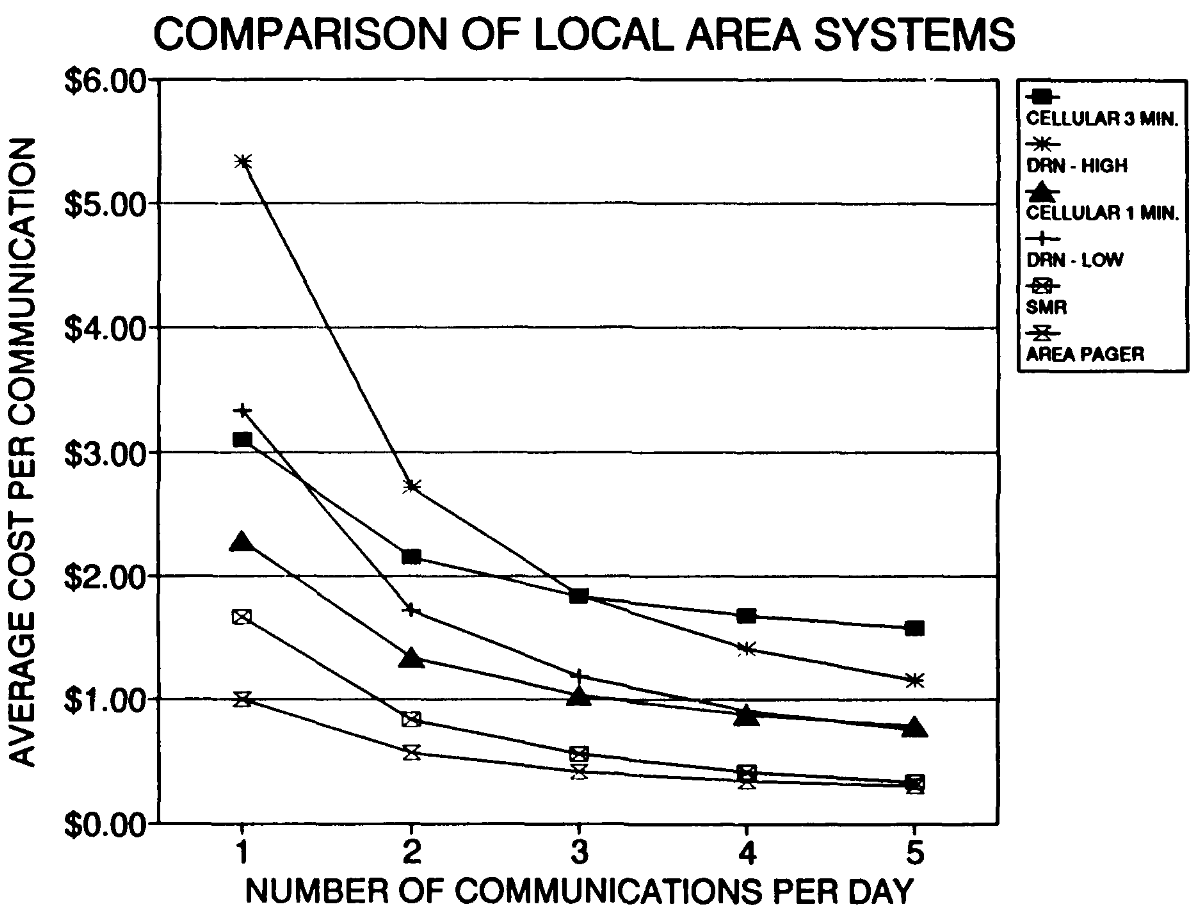

Figure 45. Comparison of Local Area Systems

generally required to accommodate voice. This requires a greater amount of equipment and results in higher user charges. In certain instances a premium charge may also be applied to voice services because, for some users, voice is more convenient, familiar, and easy to use than a keyboard. The key to minimizing the total monthly cost of voice systems is keeping the number of calls and conversations as short as possible.

4. Coverage

In general, systems which provide universal coverage (satellite and meteor burst) are more expensive than terrestrial systems which provide coverage only in populated areas. Likewise, networked cellular, SMR, and mobile data rates are more expensive than local rates. This is because additional equipment, software, and communication circuits are required to network the separate sites and administer the system. Higher rates may also be charged because of the additional value nationwide and regional service provides to the user.

5. Cellular Radiotelephone Rate Structure

Networked cellular-radio costs are considerably more expensive than local-area cellular rates. This is due primarily to the imposition of daily roaming fees for each system and the requirement to pay long-distance telephone charges. These charges do not appear to be onerous for the occasional roaming user. However, frequently using many

different cellular systems, not holding communications to the minimum time possible, or a combination of both can result in a hefty bill.

Assuming attempts to network SMR on a nationwide basis are successful, the use of cellular radio in trucking applications may decline. This is primarily due to the difference in voice rate structure, the elimination of roaming fees, and the capability to send routine messages via data instead of voice.

Under this cost model, the fully-allocated mobile voice expenses listed in the AMSC FCC filing are lower in total cost than cellular roaming. Cellular roaming service charges and most of the long-distance expense are eliminated because of the satellite's ability to provide nationwide coverage and the capability of the network operations center to route the call to the nearest earth gateway. Assuming both the cellular and AMSC rate structures do not markedly change, roaming users who do not require uninterrupted nationwide voice coverage might find it cost favorable to own higher performance mobile satellite terminals.

6. Combined Use of Digital and Cellular Equipment

The addition of a cellular telephone to a digital satellite or meteor-burst equipped vehicle provides voice capability in the more densely populated areas. This combination may be useful when data messages are cumbersome or voice discussions are required. Although this combination is

not modeled, enough information is provided above to enable the reader to determine the additional total and average costs for a given level of use.

7. Effect of Equipment Costs on Fully Allocated Monthly Expenses

Monthly charges for user equipment in the above model were determined by amortizing the terminal expense over a period of 60 months at a 12% cost of capital. As shown in Figure 46, fixed equipment costs are about $22 a month per $1000 of capital expense.

This graph shows the effect of cost reductions due to production volume efficiencies, technology improvements, and competition. A 50% reduction in price on a $4000 terminal will result in an amortized cost savings of approximately $44 per month or $528 a year. In an environment where adoption of a communication technology is effected by cost, reductions in equipment prices may increase the number of users. Cellular telephone is one example where declining equipment costs (from around $3000 down to as low as $200) has been partially responsible for increasing the number of subscribers.

As shown in the cost model diagram above (Figure 31), total cost to the user is a function of amortized equipment expenses and monthly fixed and variable communication charges. In certain cases the selection of a system with low-cost equipment and high usage charges may result in lower total costs than a system with high terminal costs and low

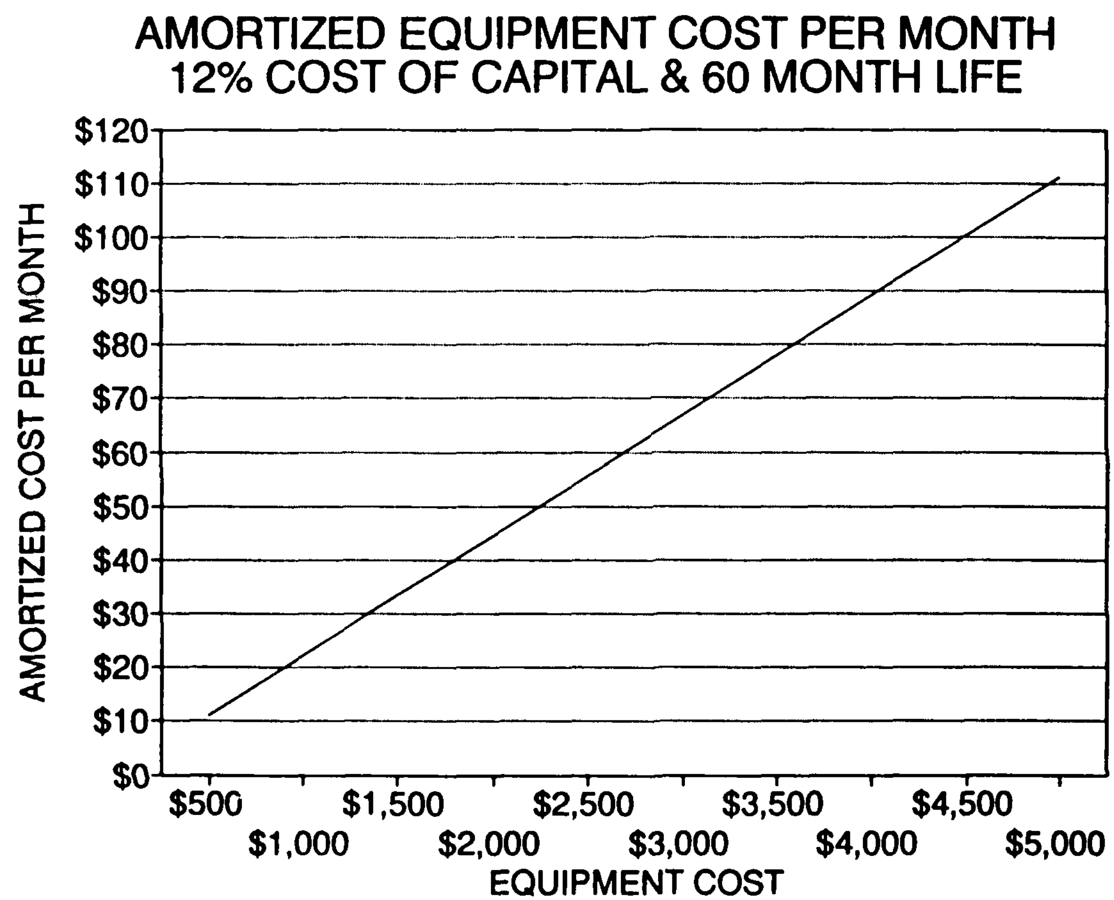

Figure 46. Amortized Equipment Cost Per Month
12% Cost of Capital and 60 Month Life

communication charges. This is conceptually illustrated in Figure 47. For infrequent communication requirements, low-cost cellular telephone equipment combined with relatively high communication charges may be more cost effective than the alternatives. For example, use of a roaming cellular telephone ten times per month for one minute would result in fully-allocated charges of approximately $73. With the exception of a combined nationwide pager and long-distance telephone (which requires the driver to stop and leave the vehicle), this total cost is less than any other currently operating nationwide or regional system modeled above.

8. Effect of Distance on Communication Charges

Costs are distance insensitive for the radio portion of satellite and meteor-burst communications. Likewise, costs for using packet-switched networks to connect mobile satellite ground stations, meteor-burst master stations, Motorola CoveragePLUS SMR sites, and mobile data networks are also range insensitive. Public long-distance telephone charges increase with the communication distance.

The above cost analysis makes a simplified assumption that all data exchanges and long-distance cellular telephone conversations take place at the 3000 mile range. In most cases this will not be true and the total communication costs for systems using the long-distance telephone system will be less. This will change the calculated cost curves. For data-only systems, the cost differences will not be that large

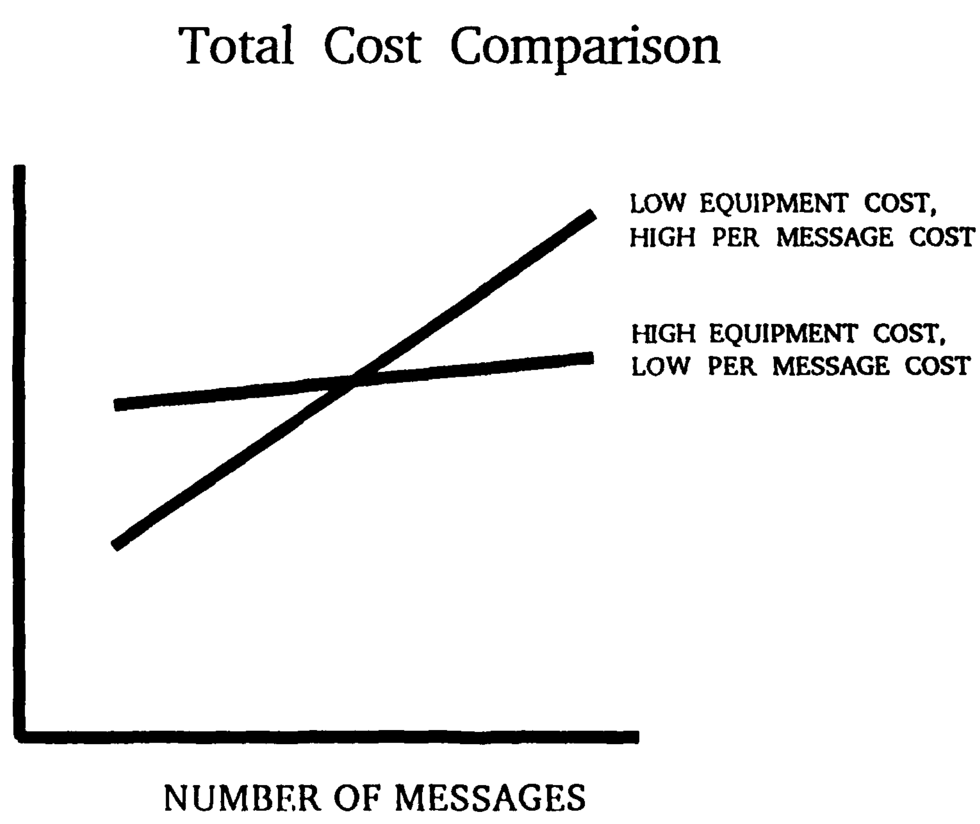

Figure 47. Total Cost Comparison

because of the speed and efficiency of data transmission. Cellular and SMR systems will show a greater percentage change because of the length of times required for voice communications. These effects should be taken into account when evaluating mobile communications alternatives for specific applications. Figure 48 conceptually illustrates the effect of distance and rate sensitivity on total costs.

E. CONCLUSION

Mobile communication systems have generally been priced according to service capabilities and features. When new systems with increased capabilities become operational, or fully-allocated user costs are lowered, competing technologies will come under pressure to reduce rates or increase the level of service. The differences between Motorola CoveragePLUS SMR, the proposed AMSC voice rates, and current costs of cellular roaming are one example. In this case, roaming users may change communication systems if the roaming cellular rate structure is not adjusted accordingly.

The large difference in the per-message cost of voice and data communications will encourage frequent communicators and operators of large fleets to use text messages as much as possible. Although not modeled above, direct driver input of data into computerized dispatching and tracking systems should reduce the number of dispatchers required.

Conceptual Illustration of Rate and Distance Effects On Total Communication Costs

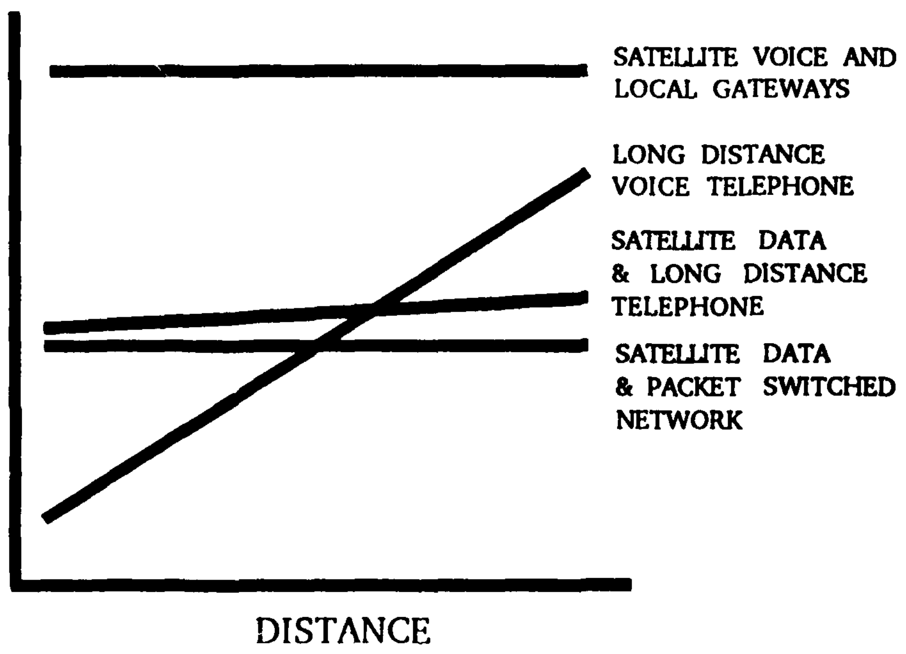

Figure 48. Conceptual Illustration of Rate and Distance Effects on Total Communication Costs

Given the nature, operation, and planned expansion of the user's business, the challenge is to decide which, if any, mobile communication technology and service is the most beneficial and cost effective. Investing in a system with unnecessary capabilities or relying exclusively on mobile voice systems may lead to expenditures which are greater than necessary. Conversely, investing in a system with reduced capabilities may cause unnecessary inefficiencies, a loss of market share, and revenue. In those cases where a mobile system is used infrequently, the average cost per communication may be so high that the system is not economically justified.

IV. SATELLITE TRACKING AND COMMUNICATIONS QUALITATIVE COST BENEFIT ANALYSIS

A. PURPOSE AND SUMMARY

The purpose of this analysis is to verify the claims made by satellite system proponents and to determine if these systems can be expected to make general economic sense for the trucking industry. Subject to the assumptions, data, and limitations discussed below, the analysis suggests that available Geostar and OmniTRACS technologies may be cost effective for certain segments of the trucking industry. Although terrestrial systems are not modeled, the analysis also suggests that these systems may be cost effective if uninterrupted coverage and continuous communications are not required.

B. BACKGROUND

Since the mid-1980's, proponents have made many claims about the efficiencies and cost-avoidance benefits of RDSS, and LMSS. Most of these statements have been made about the benefits which will accrue to the transportation industry, particularly long-haul trucking. Generally, these assertions have not been quantified because the services did not exist and there was a lack of data.

On the surface, the Geostar 2.0, 2C, and OmniTRACS technologies look expensive. Purchased mobile terminals range

in price from roughly $3000 to $4500, depending on manufacturer, features, and quantity. Monthly service fees run from $35 on up. Software to operate the systems on an office personal computer costs about $3000. In addition, communication charges are incurred to connect the company's computer with the satellite-system network-management center.

On the other hand, trucking companies have significant communication costs and inefficiencies, such as deadheading, lost-driver productivity due to time involved in contacting the dispatcher, and suboptimal dispatching because of a lack of timely location information. Competitive pressures have become intense since the trucking industry was deregulated in the early 1980's, and several thousand firms have gone out of business [Ref. 45]. Rates have generally fallen, saving the economy billions of dollars. In this environment, any cost effective method which can reduce trucking expenses or increase efficiency should be seriously considered.

C. LIMITATIONS OF THE ANALYSIS

Reasonably firm cost figures are obtainable for the Geostar and OmniTRACS systems. Trucking industry statistical data are also readily available. This analysis uses these data to derive a qualitative evaluation of the costs and benefits. Qualitative is stressed because the actual costs and mileage statistics for real firms will vary from the model categories of trucking firms used in the analysis. The

analysis also makes "educated assumptions" about how trucking firms currently operate and will modify their operations using this new technology. This is undoubtedly different from what actually occurs. Because of these assumptions and limitations, the numeric results of the cost benefit model can only be used as a indicator to determine if the Geostar and OmniTRACS systems may make economic sense. Within the context of this analysis, the results should not be used as a decision tool for any specific firm, and should not be used to determine the relative advantages of one satellite system over another. However, the methodology and spreadsheet template in Appendix C can be used with specific motor carrier financial and operating data to aid in deciding whether to use this new technology as well as which satellite system to select.

D. METHODOLOGY

1. Spreadsheet Model

The spreadsheet model, illustrated in Figure 49 and contained in Appendix C, has three broad categories of items which can be affected by RDSS and LMSS. These categories are revenue increases, expense reductions, and cost increases. The revenue category projects income growth through the ability to provide value-added services. The expense-reduction category includes deadhead avoidance, driver and equipment productivity, dispatcher and layover expense reductions, decreases in security, safety, and insurance

Spreadsheet Model

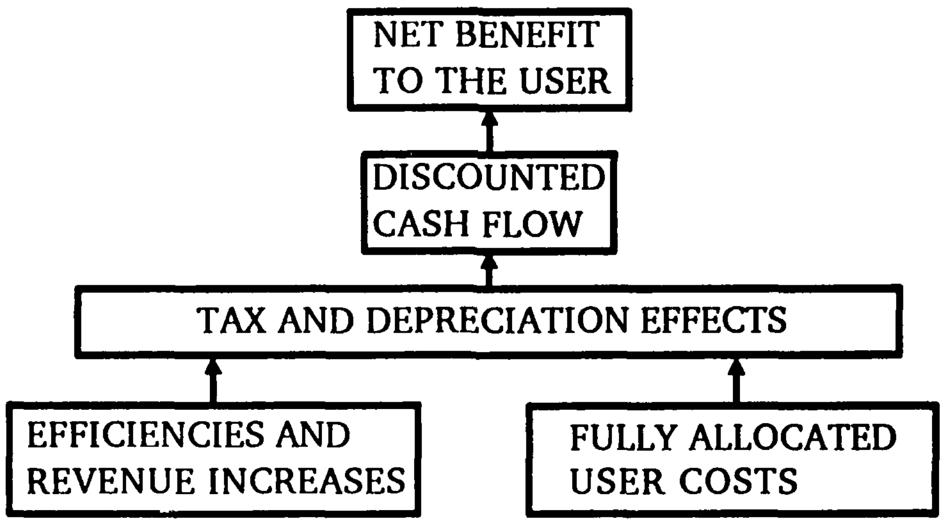

Figure 49. Spreadsheet Model

expenses, as well as administrative and tele-communications expense reductions. The cost-increases section covers monthly charges associated with RDSS and LMSS service, telecommunications expenses for connection to the network management center, and maintenance expenses associated with the ground equipment.

The calculations and assumptions made in the model are self-explanatory except for driver and equipment productivity and deadhead avoidance. Although in reality these categories are interrelated, the spreadsheet treats them separately. The model measures the effect of deadhead avoidance by increasing the percentage of loaded miles driven. The additional loaded miles are multiplied by the contribution-margin per mile (revenue minus variable costs) to derive the amount of expense savings or additional gross profit.

Input for the driver and equipment productivity calculation is based on the additional hours per month that the vehicle can be operated. Driver and equipment productivity increases are measured by the model as the <u>added</u> loaded distance, above the amount computed in the deadhead-reduction category, that the vehicle is able to travel during a one-month period. The additional <u>loaded</u> miles are determined by multiplying the total extra distance traveled by the revised loaded-mile percentage taken from the deadhead-avoidance category. The additional loaded miles driven are multiplied by the contribution per mile to give the impact on

operating profits or expenses. The calculated increases in both categories are then added together to give the total impact on operating profits or expenses.

The total monthly cash flow savings from the use of a satellite system is applied by the spreadsheet model against the purchase and installation cost of the fixed and mobile equipment. Lease and financing options are not performed. The analysis assumes that the firm is federally taxed at the highest rate and that earnings are sufficient to take full advantage of depreciation writeoffs. State taxes are not included. The model accounts for tax effects and depreciation over six and eight-year periods using the five and seven-year Modified Accelerated Cost Recovery System (MACRS) and the optional straight line methods. The yearly depreciation percentages are based on a midyear convention [Ref. 46]. The useful economic life of the equipment is expected to be the length of the depreciation period. Disposal value is assumed to be zero. Inflation factors are not included. The model evaluates the cash flows under the regular payback, net present value (NPV), and internal rate of return (IRR) procedures.

2. Approach Used in the Qualitative Analysis

A conservative approach is used in the qualitative cost benefit analysis. All figures used in the study are taken from industry statistics, marketing studies, and rate

quotes. Interpretations of industry data, assumptions, and statistics are discussed in other sections below.

Only deadhead reduction, driver and equipment productivity, and telecommunications costs are evaluated within the model's expense-reduction category. All cost-increase items associated with the use of Geostar or OmniTRACS are included. Revenue increases, financial and operational benefits from two-way communications, and other expense-reduction items have been excluded because adequate information is not available. These items are expected to be a factor when the technology is implemented; however, without meaningful data their use is speculative and makes the analysis less conservative.

Only one depreciation schedule was used in this study. This was done to reduce the volume of output and to simplify the analysis. Because of the rapidly-evolving technology, a five-year depreciation schedule is more representative of the useful economic life of the equipment. The five-year MACRS schedule was used because most firms would opt for an accelerated depreciation writeoff to reduce their tax liability.

E. METHODS USED TO EVALUATE INVESTMENT IN SATELLITE TECHNOLOGY

1. Payback Period

The payback period is the amount of time necessary to recover the cost of the initial investment from profits or

savings. After the initial outlay, cash flows back in to the firm at the forecast rate until the project breaks even from an accounting standpoint. The shorter the payback period the greater the project's liquidity. Longer-term future cash flows are generally regarded as being riskier than shorter-term cash flows. Thus the payback period can be used as a rough indicator of both the liquidity and riskiness of a project. A major limitation of the payback period is that it does not take into account the cost of capital used to finance the project [Ref. 47:p. 15].

2. Net Present Value (NPV)

The net present value method takes into account the time value of money (dollars which are received sooner are more valuable than dollars that flow in later) and the cost of capital used in financing the project. The discount rate (cost of capital or interest rate) supplied by the user is applied by the model to calculate the present value of the future cash inflows, before and after depreciation and taxes. The discounted cash flows are summed and the cost of the initial investment is subtracted. If the NPV is positive then the rate of return is greater than the cost of the capital used to finance the project. In this case, the project should be accepted. If the NPV is negative, the project should be rejected. If two projects are mutually exclusive, than the project with the highest NPV should be accepted. [Ref. 47:pp. 14-15]

3. Internal Rate of Return (IRR)

Like NPV, the internal rate of return method takes into account the time value of money. The internal rate of return is the discount rate which equates the present value of the project's expected cash inflows with the present value of the project's expected costs. The IRR is simply the NPV formula solved for the particular discount rate which forces the NPV to zero.

If the internal rate of return exceeds the cost of the funds used to finance a project then a surplus will remain after paying for the capital. Undertaking a project whose IRR exceeds the cost of capital adds value to the firm. Conversely, taking on a project with an IRR less than the cost of capital will result in a loss to the company. This breakeven characteristic makes the IRR useful for evaluating capital projects and allows the decision maker to think in terms of rates rather than dollars of net present value [Ref. 47:pp. 16-18].[1]

[1]The IRR methodology should be used with caution. A polynomial equation of n time periods is solved for the interest rate r which forces the NPV to zero. Since the equation is of degree n, it has n possible roots or IRR solutions. Computer-spreadsheet IRR algorithms can possibly converge on a solution which would mislead the user. For this and several other reasons which are beyond the scope of this thesis, the use of NPV is generally regarded as superior to the IRR criterion [Ref. 47:pp. 17-18].

F. SOURCES OF DATA

1. Financial and Operating Statistics

Financial and operating statistics for long-haul carriers were obtained from the American Trucking Association's (ATA) "1986 Motor Carrier Annual Report" [Ref. 48]. This document contains consolidated class I and II operating statistics for carriers regulated by the Interstate Commerce Commission (ICC). Class I carriers are defined as those companies which have an annual revenue of $5,000,000 or more. Class II carriers have a yearly revenue less than class I but greater than $1,000,000. Class III carriers are those firms which have annual revenues less than $1,000,000 and are not included in this analysis. Also not included in this analysis are private trucking fleets and household goods carriers. Extracts of data from the ATA report and calculated per-unit operating statistics are contained in Appendix D.

2. Other Sources of Data

In June 1985, the Marketing Research Bureau, Inc. (MRB) published The Truck Transportation Market--Communication and Positioning Systems [Ref. 49]. This detailed and high-priced subscribers-only report was based on 441 fleet respondents operating primarily for-hire as common and contract carriers. The survey sampled motor carrier needs and attitudes on improved office-to-driver communications, automatic vehicle location, and other related areas. The discount rate, frequency of contact between driver and office,

average percentage of loaded miles and expected improvements from RDSS and LMSS are obtained from this report.

Geostar, OmniTRACS, and nationwide paging costs were obtained from the equipment and service providers. Rates for determining long-distance communication costs with satellite-system network-management centers were supplied by American Telephone and Telegraph (AT&T). Cost information sources are referenced in Chapter II.

G. DATA MANIPULATION

1. Operating Cost Model

To ensure this analysis was conservative, operating costs were computed from two sources of data in the ATA report. One set of per-mile operating costs was determined by dividing the linehaul cost category amount by the number of linehaul miles driven. Additionally, a variable and fixed cost model was also constructed. This model allocated the expenses associated with operating vehicles as variable costs and all other expenses as fixed costs. Depreciation was not taken into account. These operating costs were determined by totaling the variable expenses and dividing by the number of linehaul miles driven. The two sets of operating costs were compared and the largest figure for each category was used.

Information on the fixed and variable cost model is contained in Appendix D.

2. Nationwide Paging Charges

A limitation of the Geostar System 2.0 transmitter is that it is only one way from the vehicle to the office. This limitation can be partially overcome by using a nationwide paging system in the major metropolitan areas. The $60 cost used for this option is the average of the monthly charges of two competing services[2].

3. Telecommunication Expense Decreases and Productivity Improvements

a. Per Power Unit Operated

Total communication expenses for each carrier category in Appendix D were divided by the total number of linehaul power units operated (including rented vehicles) to determine average company communications expenses per linehaul unit. These figures varied above and below the $1800 per power unit yearly average communication costs reported in the MRB survey [Ref. 49:p. 8]. To be conservative, only 75% of the communications expenses computed from the ATA report were allocated for communications with drivers.

This study assumes that a routine telephone conversation between driver and management takes from 15 to 30 minutes. This includes the time required to get to a telephone and return to the highway (deceleration, exit, locate the telephone, actual waiting and connect time, reenter the highway and return to speed). Although telephoning can be

[2] Cue and Metrocast, 1988.

done with other activities which take place anyway, such as refueling, eating, etc., the mutual effects of these activities are disregarded because of a lack of data. Each reduction of a 15-minute communication stop results in an increase of ten miles driven (15 minutes per stop times a 40 MPH average speed). Likewise, the elimination of a 30-minute stop allows an additional 20 miles to be driven. The model measures this productivity gain as an increase in contribution margin (additional revenue earned minus the variable costs of operating the truck over the extra miles driven).

b. Effects of Geostar and OmniTRACS

The assumption is made that Geostar System 2.0 transmitter will reduce the requirement to call in by 50%, since the dispatcher will know the vehicle's location and any information the driver needs to pass on. However, the driver will still have to check in because of the one-way limitation of the system.

For companies which require a three times per day check-in, the combined use of a Geostar System 2.0 transmitter and a nationwide pager is presumed to cut the requirement to call the dispatcher by an additional 50%. In metropolitan areas the dispatcher will be able to contact the truck and request that the driver call in or use prearranged codes to advise the actions required. All nationwide pages are stored in a computer for a period of time in case the intended recipient is out of paging range. The recipient then calls a

toll-free 800 number at his convenience and downloads any messages over the telephone. The use of a Geostar System 2.0 transmitter and a pager by a carrier who normally would call in once a day does not reduce the need for communication. This is because the driver would still need to call the computer to check for pages while he was operating outside of metropolitan coverage areas.

With the OmniTRACS and Geostar 2C transceivers, it is presumed the driver will have to check in at one-half the required rate of a Geostar System 2.0 and pager combination. This is because some items can only be quickly resolved through voice communication.

Tables 4 and 5 detail the communications reductions and time-savings calculations.

TABLE 4

AVERAGE OF 30 MINUTES PER TELEPHONE STOP

Item	Average reduction of stops/ day	Increase in productivity per month	Increase in miles driven per month	Reduction of total telephone expenses per unit per month
W/Geostar Sys II	1.00	10.5 Hrs	420	37.5%
W/Geostar Sys II & Pager	1.25	13.1 Hrs	524	44.0%
W/OmniTRACS & Geostar IIC	1.62	17.0 Hrs	680	60.0%

TABLE 5

AVERAGE OF 15 MINUTES PER TELEPHONE STOP

Item	Average reduction of stops/ day	Increase in productivity per month	Increase in miles driven per month	Reduction of total telephone expenses per unit per month
W/Geostar Sys II	1.00	5.25 Hrs	210	37.5%
W/Geostar Sys II & Pager	1.25	6.55 Hrs	262	44.0%
W/Omni-TRACS & Geostar IIC	1.62	8.50 Hrs	340	60.0%

The MRB study contains a frequency-of-contact table which shows that 37% of the sampled companies require their drivers to communicate with management every four hours or less. Since these figures suggest a frequency of communication associated with local route pickup and delivery service, they are removed from the analysis. Of the remaining 63% of the contacts, 26% report communications every eight hours and 28% every 24 hours. The remaining 9% are distributed between 12 and 48 hours. [Ref. 49:p.5]

To simplify the analysis, it is assumed that 50% of the long-haul carriers will report into management three times a day, and 50% will report in once a day. These figures are averaged to reduce the quantity of output. Monthly time

savings and additional miles driven assume a 21-day work month. Tables 6 and 7 summarize the average increases in productivity and the reductions in telephone expenses.

TABLE 6

AVERAGE TELEPHONE EXPENSE REDUCTION AND PRODUCTIVITY INCREASE THREE TIMES PER DAY CHECK IN

Item	# times check-in per day	Allocation of phone expenses	Telephone expense savings	Time savings per day 30 min & (15 min) stops
Total company communication bill per power unit operated	N/A	100%	N/A	N/A
Allocation to unequipped power unit	3.0	75%	0%	0 (0)
W/Geostar 2.0	1.5	37.5%	37.5%	45 (22.5)
W/Geostar 2.0 & Pager	1.0	25%	50.5%	60 (30)
W/OmniTRACS & Geostar 2C	0.5	12.5%	62.5%	75 (37.5)

4. Charges for Communication with the Network Management Center

The analysis assumes that the dispatcher's computer contacts the satellite-network management center once an hour for vehicle position and communications. More frequent

TABLE 7

AVERAGE TELEPHONE EXPENSE REDUCTION AND PRODUCTIVITY INCREASES ONE TIME PER DAY CHECK IN

Item	# times check-in per day	Allocation of phone expenses	Telephone expense savings	Time savings per day 30 min & (15 min) stops
Total company communication bill per power unit operated	N/A	100%	N/A	N/A
Allocation to unequipped power unit	1.0	75%	0%	0
W/Geostar 2.0	0.5	37.5%	37.5%	15 (7.5)
W/Geostar 2.0 & Pager	0.5	37.5%	37.5%	15 (7.5)
W/OmniTRACS & Geostar 2C	0.25	18.75%	56.25%	22.5 (11.3)

contact is possible, including on-line packet-switched network service, but for most trucking applications this is not required. The MRB study found that only 12% of the respondents required message forwarding in one hour or less [Ref. 49:pp. 16-17].

The calculated connection time is a function of the total number of Geostar or OmniTRACS-equipped vehicles operated times the message length divided by the baud rate. The number of characters in a message is assumed to be 97

(Geostar System 2.0 format), with the computer modem operating at 2400 baud. To be conservative, in accounting for variable switching times, the calculated connection interval was doubled. AT&T 3000-mile zone rates were calculated, and then discounted under the AT&T Pro America I plan ($12.00 per month fee and a 10% discount from standard rates) [Ref. 44]. Other AT&T options were evaluated, including leased lines, but all were more expensive unless the frequency of contact with the network management center was substantially increased.

5. Other Data and Model Assumptions

Other data and model assumptions are listed in Table 8.

TABLE 8

OTHER DATA AND MODEL ASSUMPTIONS

Item	Source
- On average, 75% of total miles driven are loaded	[Ref. 49:p. 86]
- Forecast 10% increase in loaded miles driven with RDSS & LMSS technology	[Ref. 49:p. 57]
- 21% IRR required 21% Discount rate for NPV calculation 3.6 Year average payback period	[Ref. 49:pp. 25-29]
- Trucks are driven eight hours per day, 21 days per month	N/A
- 34% Marginal corporate tax rate	IRS

TABLE 8 (CONTINUED)

Item	Source
- $100 Cost to install mobile units (model adds to purchase cost and capitalizes)	Vendor[3]
- $50 Yearly maintenance expense per unit	Vendor[4]
- $60 nationwide pager charge (pager rental and service)	Vendors[5]
- Geostar System 2.0: $3375 average terminal price 2C: $4100 average terminal price $0.05 for each position report and keyboard message, $45 per moth minimum charge vendor	Vendors
- OmniTRACS system $4100 average terminal price $35 per month base charge for hourly position reporting. $0.05 per keyboard message and $0.002 per character.	Vendor
- $3000 for computer software to display position and communicate with the vehicle	Vendors

6. Calculation of Monthly Service Charges

It is assumed that vehicle equipment will automatically send 744 hourly position reports each month (24 hours x 31 days). One hundred twenty-six keyboard messages per

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[3]Interview between Mr. Bob Carr, Qualcomm Inc., and the author, 12 April 1989.

[4]Interview between Mr. Bob Carr, Qualcomm Inc., and the author, 12 April 1989.

[5]Cost information sources for the remaining items are contained in Chapter II.

month will be sent to and from the network management center (NMC) and the vehicle (six messages per day x 21 working days). An average of 40 characters per communication is assumed because of the macro-message capability of both systems.

a. Geostar System 2.0 and 2C

Seven hundred forty-four hourly position reports and 126 keyboard messages per month at $0.05 each equals $43.50. The minimum monthly service charge is $45.00.

b. OmniTRACS

One hundred twenty-six messages at $0.13 each ($0.05 per message plus 40 characters times $0.002) plus $35 per month base service charge equals $51.38.

c. Rationale for the Use of $45.00 per Month in the Analysis

As stated above, this analysis is performed to determine if the use of satellite tracking and communication technologies <u>may</u> make economic sense for the trucking industry. The analysis is <u>not</u> intended to compare the two competing systems with each other on the basis of costs or benefits. The $6.38 difference in monthly charges equates to $76.56 per year. When applied to the assumed purchase price, depreciation schedule, tax and discount rates, the differences in net present value (NPV) and internal rate of return (IRR) is approximately $175 and three percent, respectively. These values are exceeded by the imprecision of the operating cost

model and the figures used for operating statistics, costs, and the assumptions regarding projected improvements. For these reasons, combined with the need to reduce the volume of model output, the monthly service charge for both systems is established at $45.00.

H. QUALITATIVE MODEL OUTPUT

The spreadsheet model was run using both 75% and 85% initial loaded mileages. The 75% statistic was obtained from the MRB study. The 85% figure was used because some carriers report loaded-mile operations greater than 75% [Ref. 49:p. 86]. To establish a range of output, two communication stop and mileage categories were run for each initial loaded-mile assumption:

a. Upper-bound productivity increase--Reduction in number of 30-minute communication stops. Decline in deadheading increases loaded miles by 10%.

b. Lower-bound productivity increase--Reduction in number of 15-minute communication stops. Decline in deadheading increases loaded miles by 5%. Carrier classification categories are:

Carrier Classification	Abbreviation
Class I General Freight	Cl 1 GF
Class II General Freight	Cl 2 GF
Specialized Common Carrier Class I	SCC CL 1
Specialized Common Carrier Class II	SCC CL 2
Contract Carrier Class I	CONT CL 1
Contract Carrier Class II	CONT CL 2

Qualitative model output showing monthly savings, payback period, net present value and internal rate of return for the use of Geostar System 2.0, Geostar System 2.0 and a nationwide pager, Geostar System 2.C, and OmniTRACS are shown in Tables 9 to 12. Qualitative graphic output for monthly savings, net present value, and internal rate of return is displayed in Figures 50 through 61.

I. EVALUATION OF MODEL OUTPUT

The following limitations and assumptions of the model must be considered before making any overall judgments.

1. Tax Effects

Significant cash flow benefits are gained from depreciating the mobile terminals. Firms which are unable to take full advantage of depreciation writeoffs may find the investment less attractive.

2. Discount and Interest Rates

The 21% discount rate used in the analysis was taken from the 1985 Marketing Research Bureau, Inc. (MRB) report. During the late 1970's and early 1980's inflation and interest rates were at historical highs. Since then interest rates and inflation have declined to much lower levels. As a result, the discount rate and internal rate of return required by trucking firms may now be less than the 21% MRB statistic. If this is the case, the qualitative analysis net present value (NPV) evaluations are too stringent. A NPV sensitivity

TABLE 9

75% LOADED MILEAGE
REDUCTION OF 15 MINUTE STOPS AND A 5% INCREASE IN LOADED MILES DRIVEN

GEOSTAR 2.0	CL 1 GF	CL 2 GF	SCC CL 1	SCC CL 2	CONT CL 1	CONT CL 2
Mo Savings/Unit	$347	$99	$75	$14	$11	$17
Payback Period (Yrs)	0.8	3.0	3.9	21.6	26	17.2
NPV	$7,544	$1,150	$571	($1,034)	($1,075)	($945)
IRR	99%	35%	28%	6%	5%	8%
GEOSTAR 2.0 & PAGER						
Mo Savings/Unit	$330	$44	$27	($39)	($48)	($39)
Payback Period (Yrs)	0.9	6.8	10.7	N/A	N/A	N/A
NPV	$7,119	($264)	($668)	($2,387)	($2,585)	($2,378)
IRR	95%	17%	12%	-31%	-50%	-30%
OmniTRACS & GEOSTAR 2C						
Mo Savings/Unit	$462	$131	$115	$75	$19	$36
Payback Period (Yrs)	0.8	2.7	3.0	4.7	18.7	9.8
NPV	$10,222	$1,676	$1,318	$258	($1,165)	($735)
IRR	108%	38%	34%	24%	7%	13%

TABLE 10

75% LOADED MILAGE
REDUCTION OF 30 MINUTE STOPS AND A 10% INCREASE IN LOADED MILES DRIVEN

GEOSTAR 2.0	CL 1 GF	CL 2 GF	SCC CL 1	SCC CL 2	CONT CL 1	CONT CL 2
Mo. Savings/Unit	$739	$258	$157	$66	$82	$84
Payback Period (Yrs)	0.4	1.1	1.9	4.5	3.5	3.5
NPV	$17,639	$5,238	$2,667	$305	$748	$774
IRR	190%	77%	52%	25%	30%	31%
GEOSTAR 2.0 & PAGER						
Mo. Savings/Unit	$769	$203	$115	$13	$29	33
Payback Period (Yrs)	0.4	1.5	2.5	22.5	10.1	8.9
NPV	$18,411	$3,824	$1,588	($1,048)	($626)	($539)
IRR	197%	63%	40%	6%	12%	14%
OmniTRACS & GEOSTAR 2C						
Mo. Savings/Unit	$968	$316	$211	$135	$103	$118
Payback Period (Yrs)	0.4	1.1	1.7	2.6	3.4	3.0
NPV	$23,231	$6,447	$3,776	$1,794	$1,008	$1,357
IRR	204%	78%	56%	39%	31%	35%

TABLE 11

85% LOADED MILEAGE
REDUCTION OF 15 MINUTE STOPS AND A 5% INCREASE IN LOADED MILES DRIVEN

GEOSTAR 2.0	CL 1 GF	CL 2 GF	SCC CL 1	SCC CL 2	CONT CL 1	CONT CL 2
Mo. Savings/Unit	$426	$130	$115	$73	$60	$50
Payback Period (Yrs)	0.7	2.3	2.5	4.0	4.8	5.9
NPV	$9,595	$1,961	$1,578	$496	$182	($106)
IRR	118%	44%	40%	27%	23%	20%
GEOSTAR 2.0 & PAGER						
Mo. Savings/Unit	$423	$87	$74	($3)	$10	$0
Payback Period (Yrs)	0.7	3.4	3.9	N/A	30.3	N/A
NPV	$9,505	$852	$530	($1,465)	($1,116)	($1,372)
IRR	117%	31%	28%	-2%	4%	0%
OmniTRACS & GEOSTAR 2C						
Mo. Savings/Unit	$574	$189	$169	$125	$85	$85
Payback Period (Yrs)	0.6	1.9	2.1	2.8	4.1	4.2
NPV	$13,104	$3,183	$2,688	$1,539	$541	$525
IRR	129%	51%	47%	36%	27%	26%

TABLE 12

85% LOADED MILAGE
REDUCTION IN 30 MINUTE STOPS AND A 10% INCREASE IN LOADED MILES DRIVEN

GEOSTAR 2.0	CL 1 GF	CL 2 GF	SCC CL 1	SCC CL 2	CONT CL 1	CONT CL 2
Mo. Savings/Unit	$899	$314	$235	$150	$180	$149
Payback Period (Yrs)	0.3	0.9	1.2	1.9	1.6	2.0
NPV	$21,742	$6,676	$4,686	$2,678	$3,264	$3,452
IRR	227%	90%	72%	51%	58%	49%
GEOSTAR 2.0 & PAGER						
Mo. Savings/Unit	$955	$297	$208	$92	$143	$111
Payback period (Yrs)	0.3	1.0	1.4	3.2	2.0	2.7
NPV	$23,183	$6,240	$3,988	$971	$2,311	$1,473
IRR	239%	86%	65%	33%	48%	38%
OmniTRACS & GEOSTAR 2C						
Mo. Savings/Unit	$1,192	$432	$318	$234	$224	$216
Payback Period (Yrs)	0.3	0.8	1.1	1.5	1.6	1.6
NPV	$28,966	$9,422	$6,516	$4,356	$4,111	$3,878
IRR	247%	101%	79%	61%	59%	57%

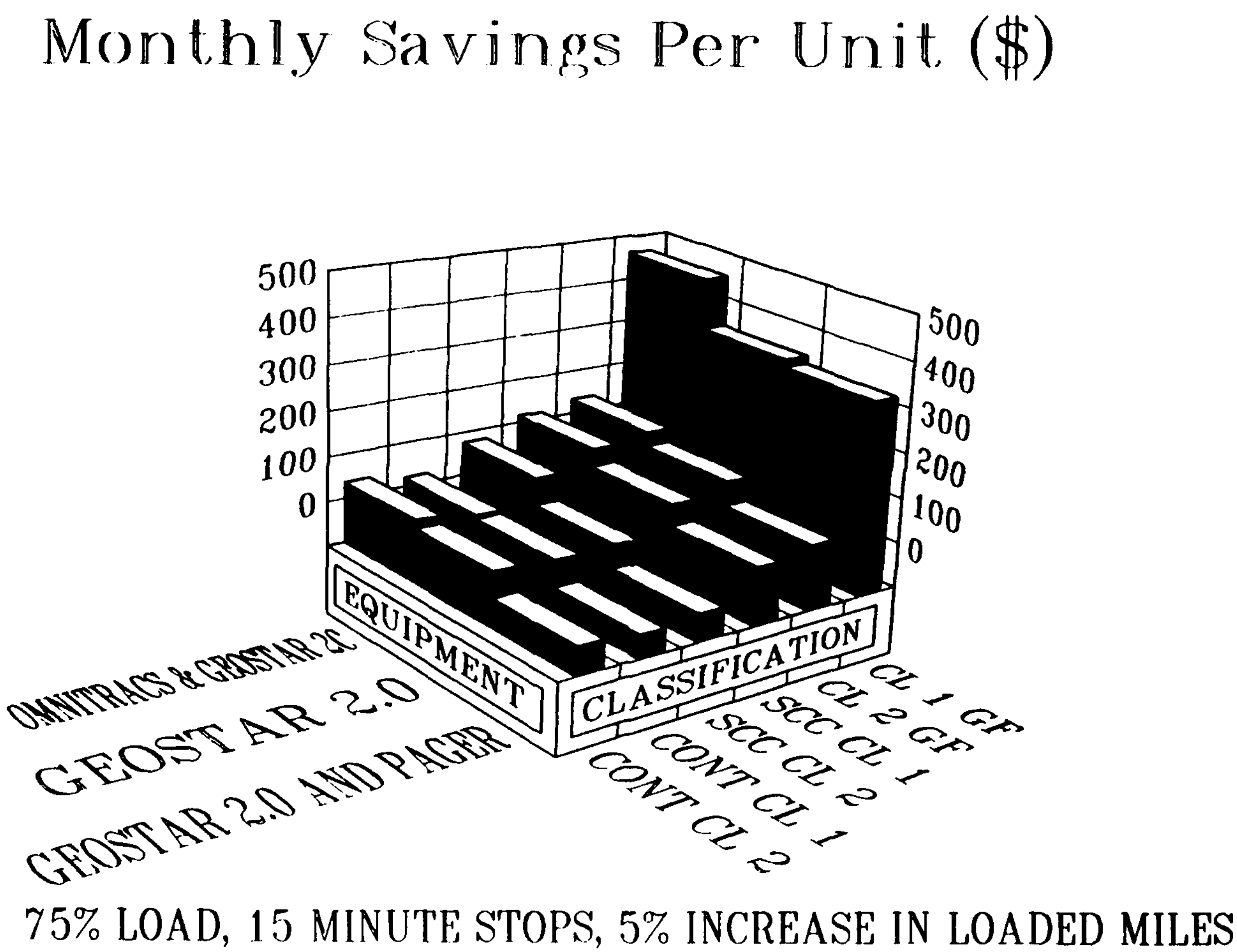


Figure 50. Monthly Savings Per Unit (S); 75% Load, 15-Minute Stops, 5% Increase in Loaded Miles

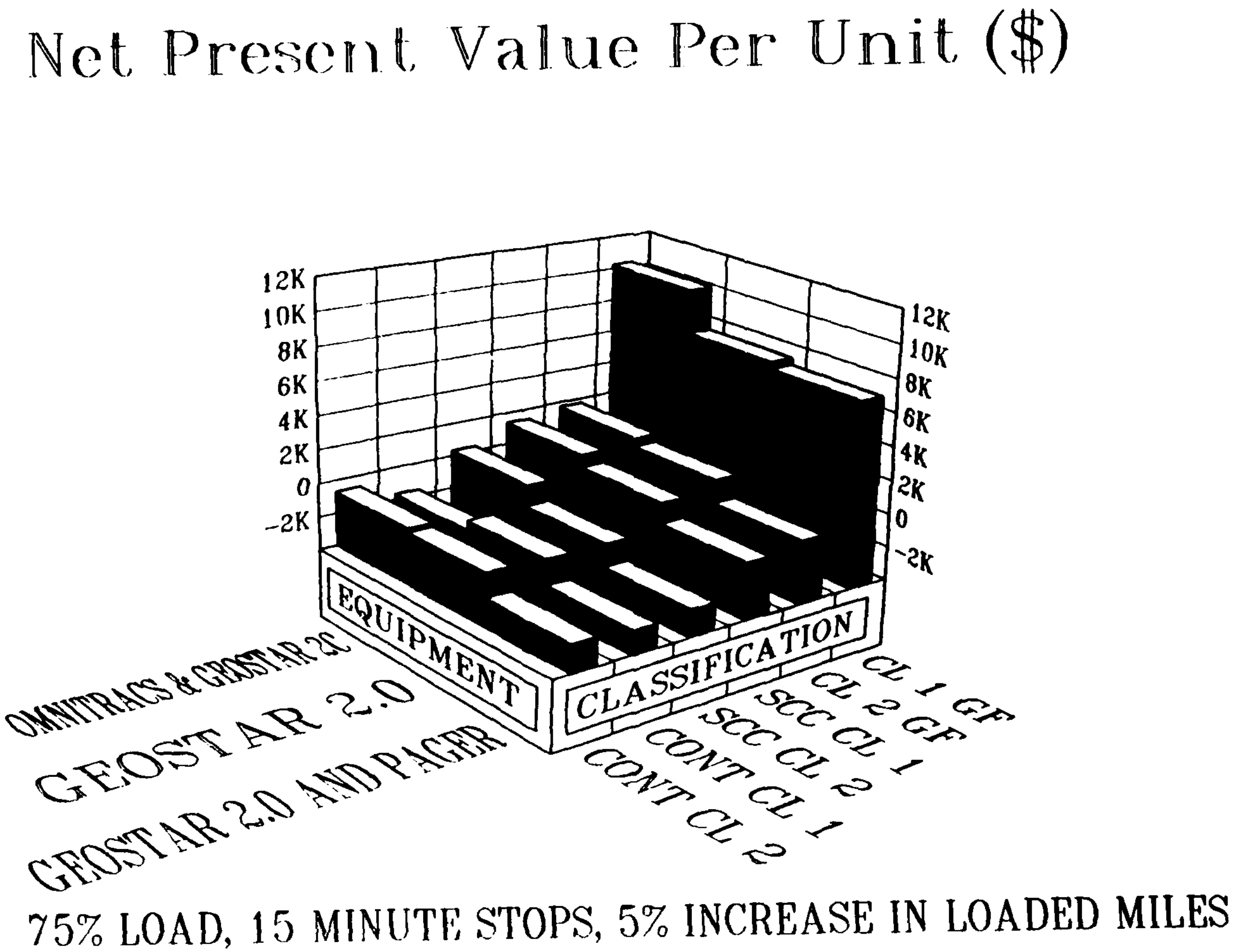


Figure 51. Net Present Value Per Unit (S); 75% Load, 15-Minute Stops, 5% Increase in Loaded Miles

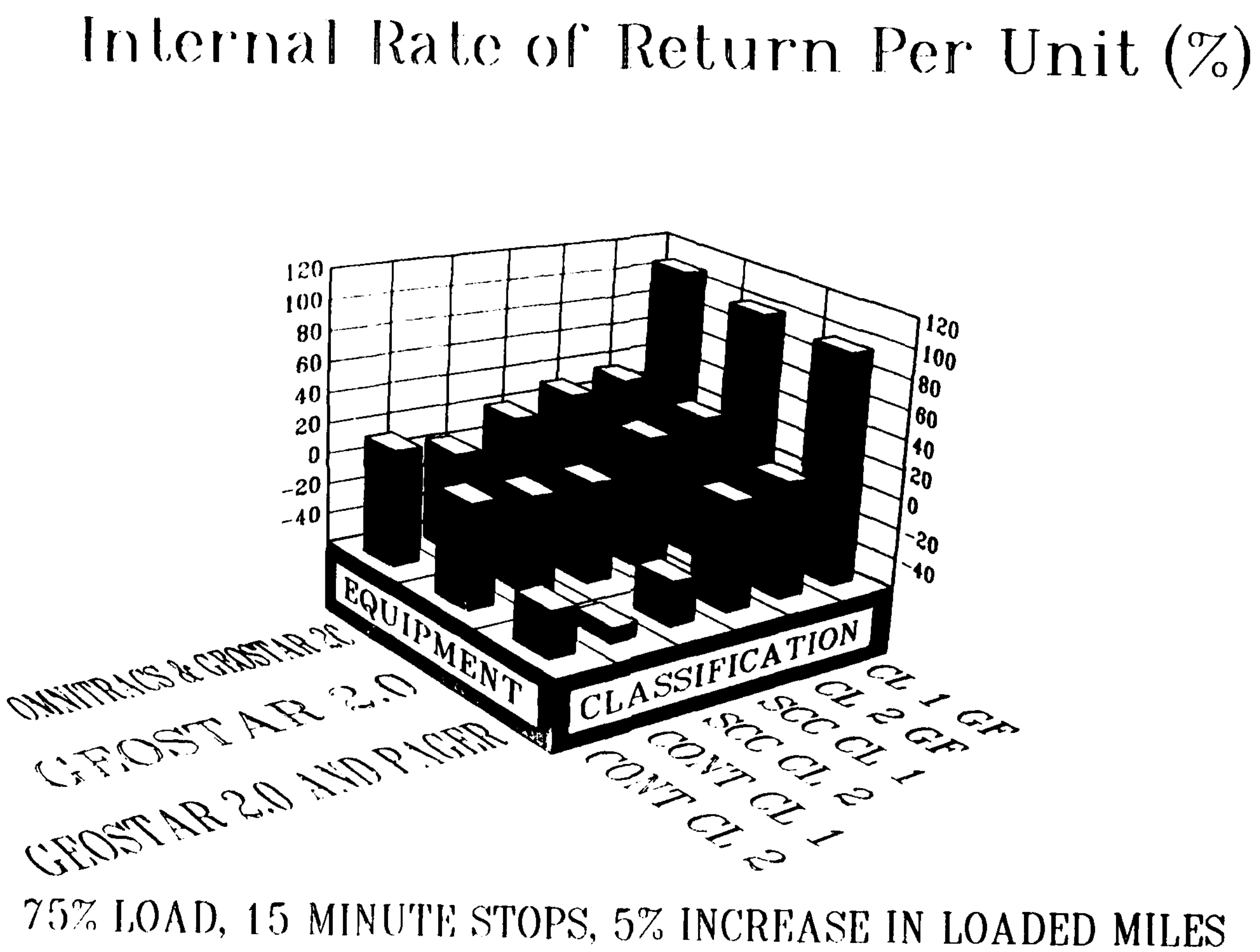


Figure 52. Internal Rate of Return Per Unit (S); 75% Load, 15-Minute Stops, 5% Increase in Loaded Miles

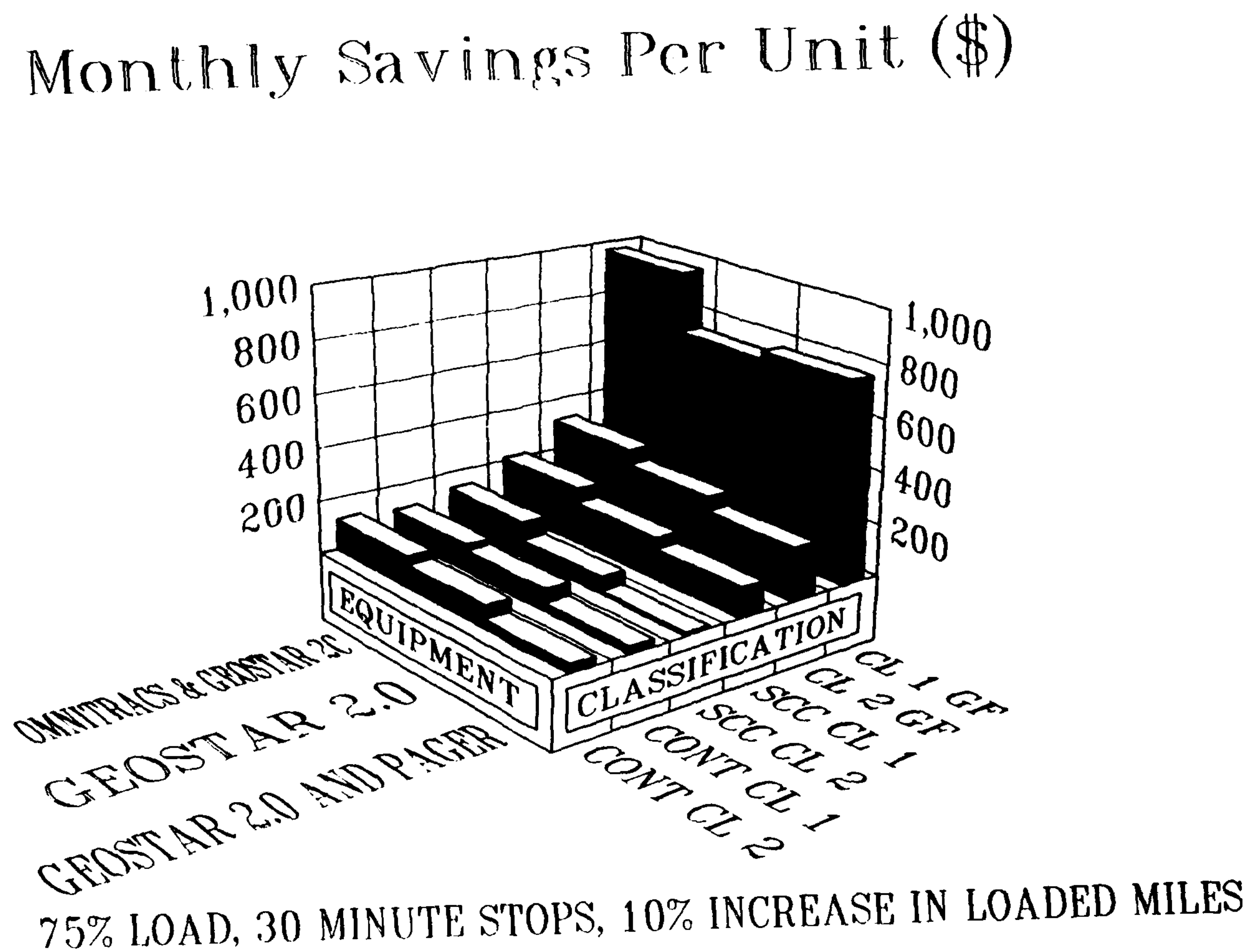


Figure 53. Monthly Savings Per Unit (S); 75% Load, 30-Minute Stops, 10% Increase in Loaded Miles

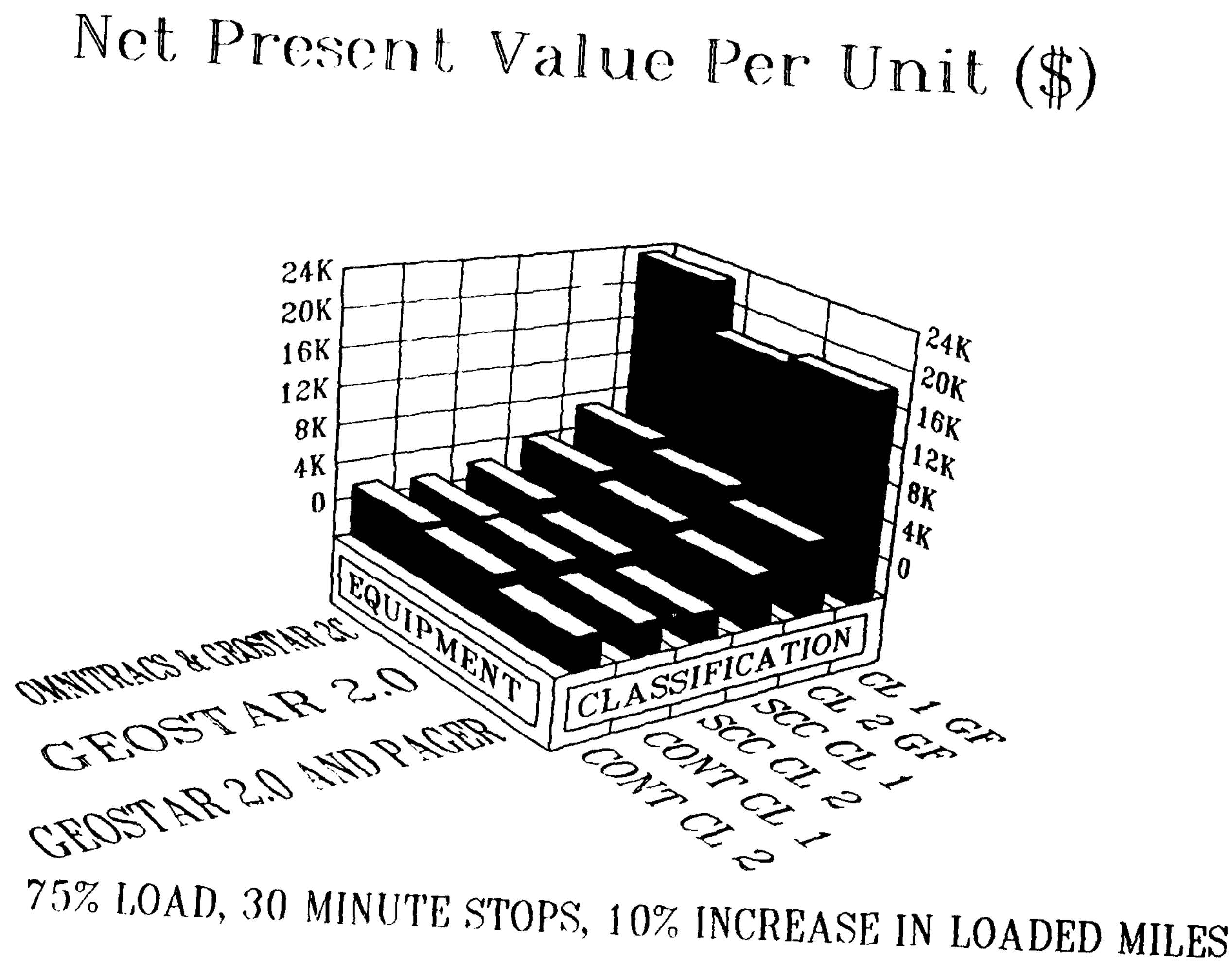


Figure 54. Net Present Value Per Unit (S); 75% Load, 30-Minute Stops, 10% Increase in Loaded Miles

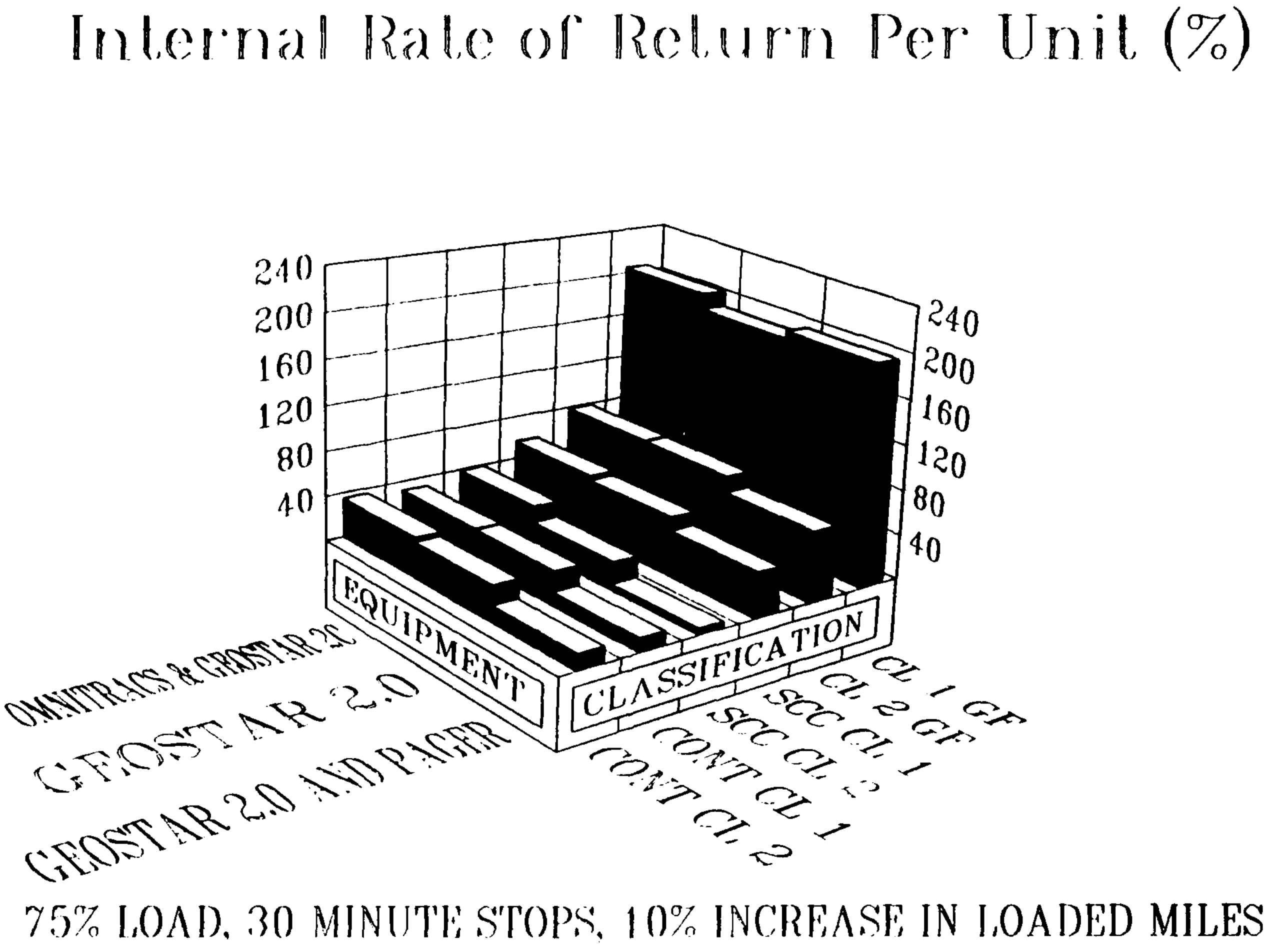


Figure 55. Internal Rate of Return Per Unit (%); 75% Load, 30-Minute Stops, 10% Increase in Loaded Miles

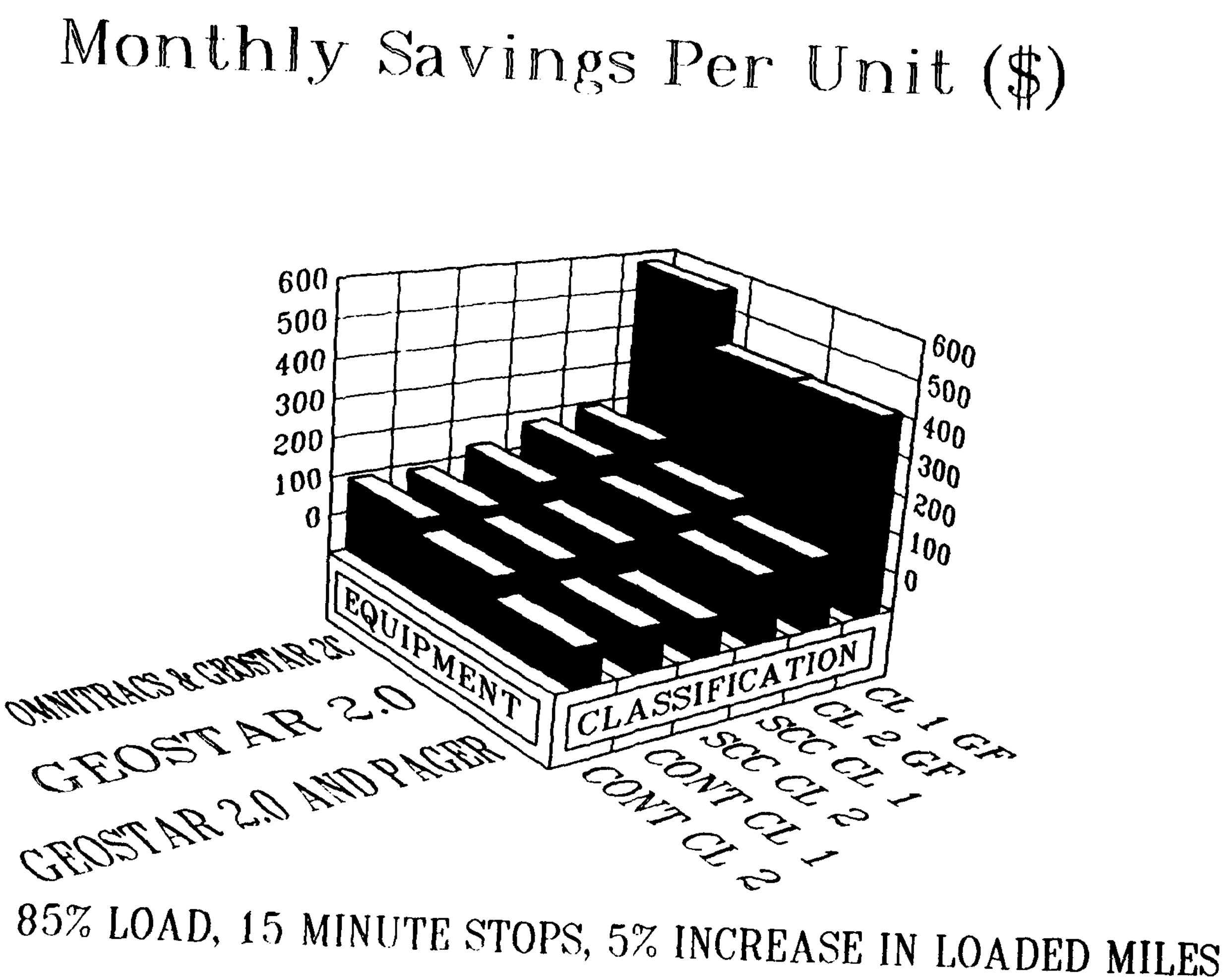


Figure 56. Monthly Savings Per Unit (S); 85% Load, 15-Minute Stops, 5% Increase in Loaded Miles

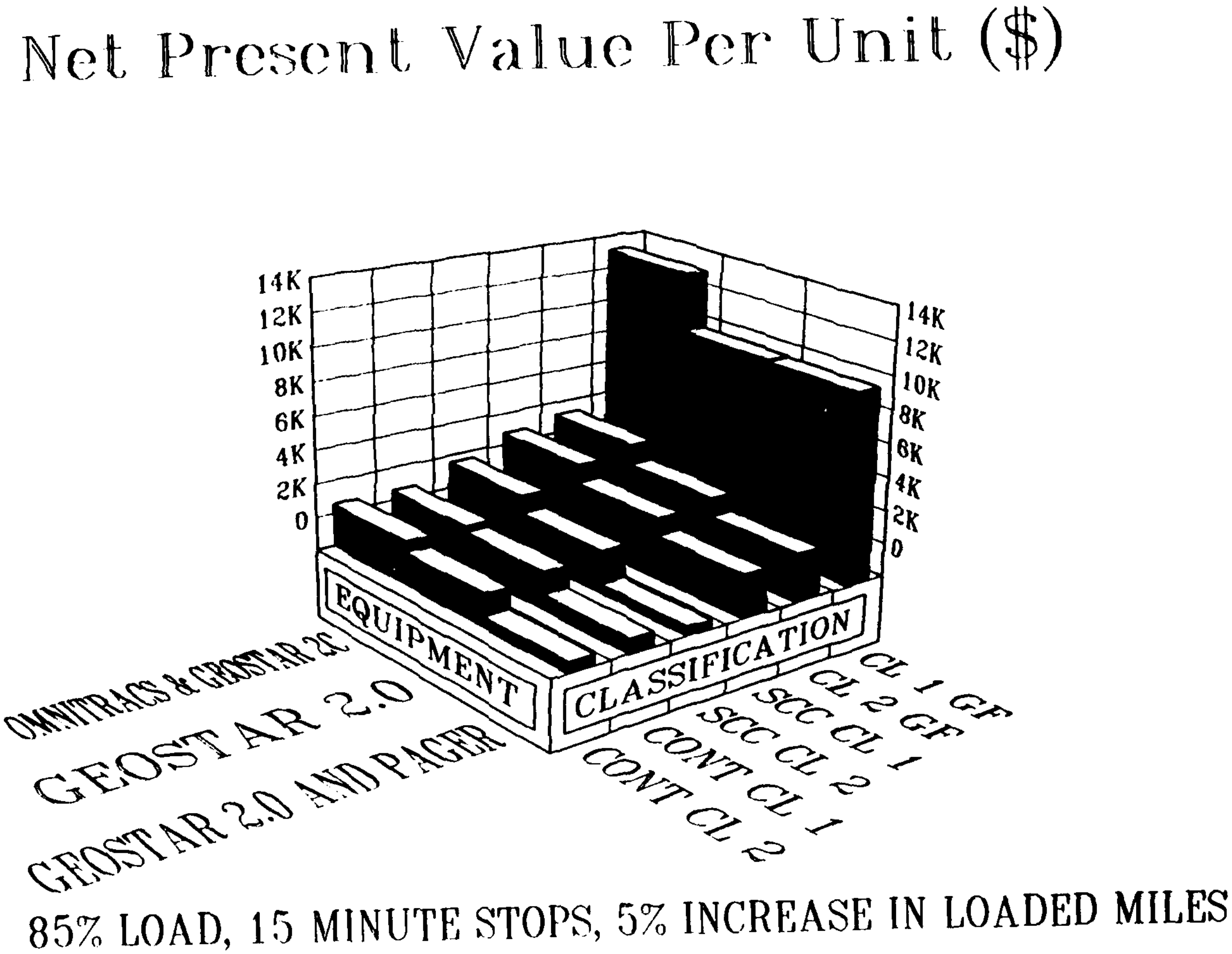
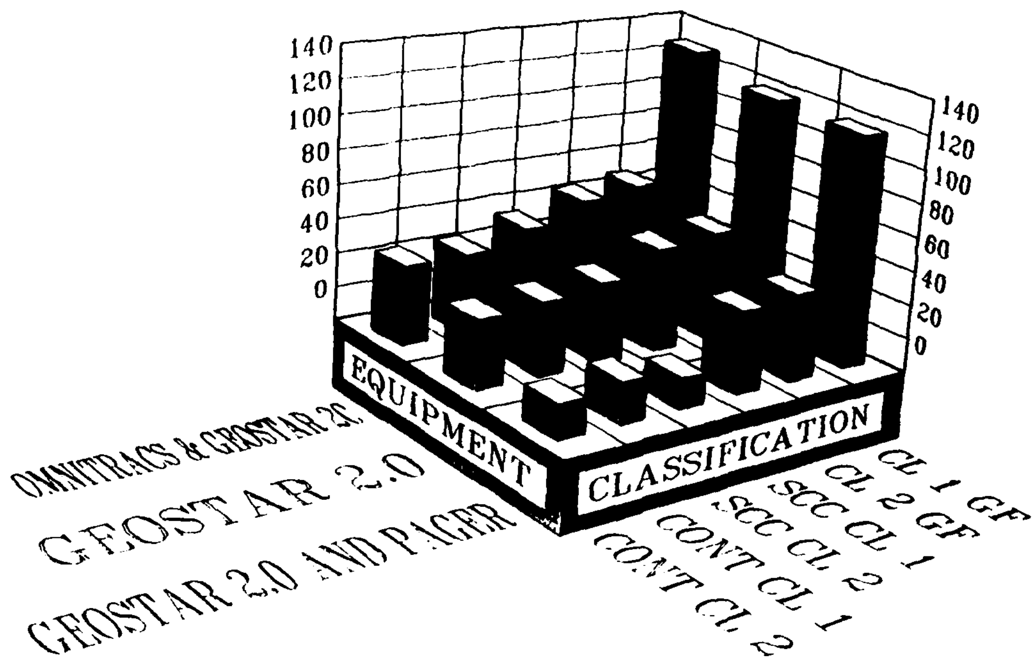


Figure 57. Net Present Value Per Unit (S); 85% Load, 15-Minute Stops, 5% Increase in Loaded Miles

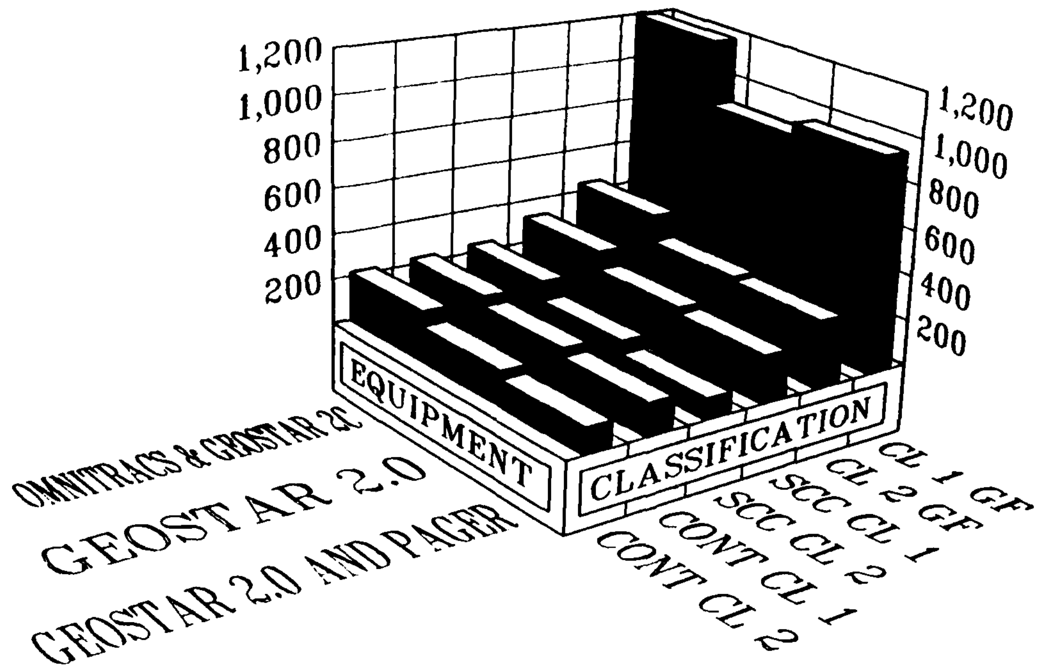
Internal Rate of Return Per Unit (%)



85% LOAD, 15 MINUTE STOPS, 5% INCREASE IN LOADED MILES

Figure 58. Internal Rate of Return Per Unit (%); 85% Load, 15-Minute Stops, 5% Increase in Loaded Miles

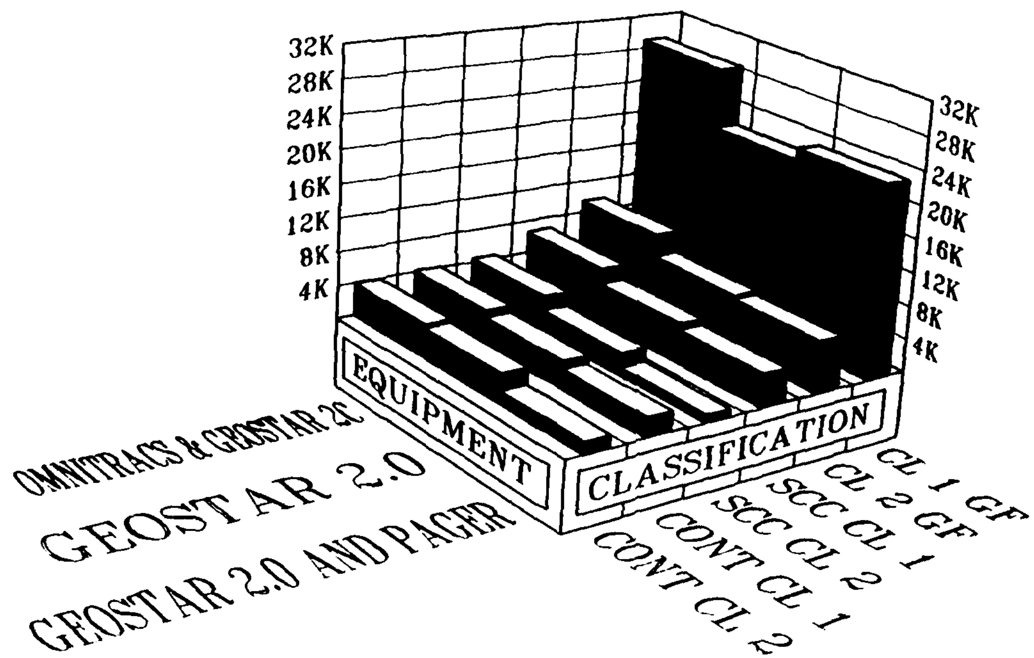
Monthly Savings Per Unit ($)



85% LOAD, 30 MINUTE STOPS, 10% INCREASE IN LOADED MILES

Figure 59. Monthly Savings Per Unit (S); 85% Load, 30-Minute Stops, 10% Increase in Loaded Miles

Net Present Value Per Unit ($)



85% LOAD, 30 MINUTE STOPS, 10% INCREASE IN LOADED MILES

Figure 60. Net Present Value Per Unit (S); 85% Load, 30-Minute Stops, 10% Increase in Loaded Miles

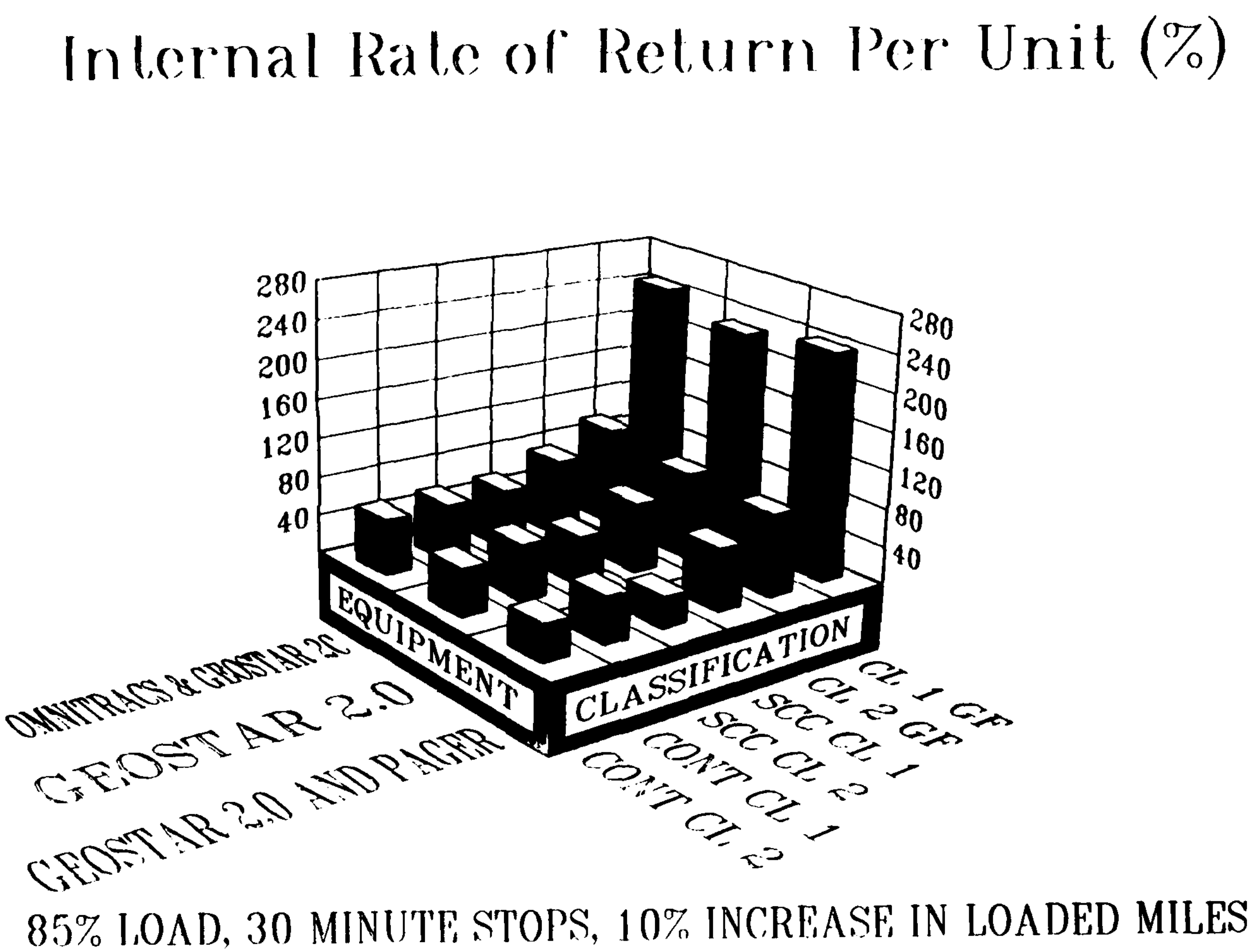


Figure 61. Internal Rate of Return Per Unit (%); 85% Load, 30-Minute Stops, 10% Increase in Loaded Miles

analysis for discount rates of 10%, 15%, and 21% is discussed below.

3. Operational Efficiencies

a. Communication Expenses

Communication expenses used in the analysis were determined from the ATA statistics listed in Appendix D, and are the average of all the firms in each reporting category. The MRB study found that the annual communication expense for 65% of the sample population was less than $1000 per power unit. The remaining 35% spent over $1000 a year for driver communication with the office. For all firms, the average annual cost per power unit for communications between the driver and the office was about $1800 [Ref. 49:p. 8].

These MRB statistics suggest that the distribution of industry-wide communication expenses is skewed to the right, with more than 65% of the trucking firms having communication expenses less than the industry average. This must be kept in mind when evaluating the average communication costs savings computed by the model.

The model probably overstates LTL carrier communication savings. This is because the larger LTL trucking firms have well-defined transportation networks and computerized data-communication systems. LTL tractor-trailers move over designated routes at a known average speed. Management can determine approximate positions and expected arrival times through past experience and dead reckoning (speed multiplied

by elapsed time equals distance). As a result, LTL drivers do not have to use the telephone as often as irregular route and long-haul TL carriers. A large reduction in telephone expenses would not be expected in this case.

b. Loaded Mile Statistics from the MRB Study

The MRB modal classification (the number which occurred most often) for loaded miles was in the 71% to 80% category and was reported by 29% of the respondents. However, about 37% of the sample estimated their average loaded miles to be between 81% and 100%. The LTL carriers, fleets with over 100 vehicles, and fleets using freight brokers, top the list with about 81%, 80%, and 79% loaded miles respectively. In these groups the proportion claiming 91% to 100% equipment utilization is also above average with 18% of the LTL sample, 19% of the 100-plus fleet size, and 15% of those using freight brokers [Ref. 49:p. 86].

These statistics show that the larger LTL firms, private fleets, and some motor carriers who use freight brokers to fill empty backhauls are achieving very high equipment mileage utilization. The use of RDSS and LMSS technology may not enable these firms to substantially increase their loaded mile percentage.

c. Time Savings and Productivity Gains

The model measures the productivity gain from reducing communication stops by assuming that the vehicle will be able to drive farther and haul more freight. Time savings

and corresponding productivity gains may be overstated because driver telephone calls can occur during stops for other purposes. When this happens the calculated savings should be reduced by the time it would have taken to decelerate, exit, locate the telephone, reenter the highway and return to speed.

As in communication expenses, LTL carriers who do not have to make many telephone calls will show less time savings and productivity improvements than other types of carriers. An alternative measure of time savings and productivity gain could be the calculation of the avoided cost of capital, or how many less vehicles could haul the same amount of freight. However, in the case where the truck simply arrives earlier at its destination and stops, the model is in error and should be changed to reflect a reduction in driver wages or some other measure associated with less operating hours.

d. System Capabilities

The Geostar System 2.0 transmitter is only capable of one-way communications from the vehicle to the office. The Geostar 2C and OmniTRACS transceivers are capable of two-way communications. The assumptions used in the analysis partially account for this difference by adjusting the amount of telephone expenses and communication stops. The model does not take into account any other operational advantages which may result from the two-way capability.

4. Variable Cost Model

The variable cost model used in this analysis evaluates all costs other than those associated with operating line-haul vehicles as fixed, although in reality many of these expenses are variable or semi-variable in nature. General cargo haulers, particularly the LTL carriers, have substantial freight terminal, payroll, computer, administrative, local pickup and delivery expenses, etc. These companies require large line-haul revenues and contribution margins to cover what are defined by the model as fixed costs. The deadhead reduction and driver and equipment productivity sections of the spreadsheet compute significant savings for carriers which have large contribution margins. As discussed previously, efficient trucking firms may find these savings and productivity increases difficult to achieve.

5. Sensitivity Analysis

The figures used in the above analysis for operating statistics, costs, and estimates of projected improvements are imprecise. This sensitivity analysis is provided to enable the reader to gauge how the spreadsheet output varies in response to a change in the inputs. The analysis is based only on the purchase price of a single mobile satellite transceiver and the amount of savings or contribution to profits after all monthly expenses have been paid (including nationwide pager rental charges). The net present value and internal rate of return calculations take into account the

same MACRS depreciation and income tax effects that are assumed in the above analysis.

a. Monthly Savings and Costs

Monthly cost increases and savings used in the qualitative analysis are composed of deadhead avoidance, driver and equipment productivity, communications expense reduction, monthly satellite-system service fees, monthly charges for communication with the network management center, and maintenance expense. Any single category or combination can be varied to change the model output. Deadhead avoidance, driver and equipment productivity are the easiest to manipulate and understand because both are measured in loaded miles. For this reason these two categories are used for sensitivity illustration purposes. Contribution margins and incremental milages are shown in Tables 13 and 14.

TABLE 13

SENSITIVITY ANALYSIS INPUTS

Carrier Classification	Abbreviation	Contribution Margin per mile
Class I General Freight	(CL 1 GF)	$1.15
Class II General Freight	(CL 2 GF)	0.43
Specialized Common Carrier Class I	(SCC CL 1)	0.26
Specialized Common Carrier Class II	(SCC CL 2)	0.19
Contract Carrier Class I	(CONT CL 1)	0.26
Contract Carrier Class II	(CONT CL 2)	0.22

TABLE 14

ADDITIONAL LOADED MILES REQUIRED TO
GENERATE INCREMENTAL CONTRIBUTION MARGINS

Monthly Increase in Contribution Margin	Additional Loaded Miles		
	CL 1 GF	CL 2 GF	SCC CL 1
$ 0	0	0	0
20	17	47	77
40	35	93	154
60	52	140	231
80	70	186	308
100	87	233	385
120	104	279	462
140	122	326	538
160	139	372	615
180	157	419	692
200	174	465	769

Monthly Increase in Contribution Margin	Additional Loaded Miles		
	SCC CL 2	CONT CL 1	CONT CL 2
$ 0	0	0	0
20	105	77	91
40	211	154	182
60	316	231	273
80	421	308	364
100	526	385	455
120	632	462	545
140	737	538	636
160	842	615	727
180	947	692	818
200	1053	769	909

b. Payback Period

The payback period is reduced by 50% for every doubling of an initial base savings or profit figure. For example, the payback period under a $20 a month return is twice that of $40, and is four times that of an $80 return.

This means that the payback period is initially very responsive to small changes in return and is decreasingly sensitive as the monthly amount of savings increases. To reach the MRB study 3.6 year average required payback requires a monthly savings of roughly $80 for Geostar and $95 for OmniTRACS and Geostar 2C. Graphs of the payback periods in Table 15 are displayed in Figures 62 and 63.

TABLE 15

PAYBACK PERIOD SENSITIVITY (YEARS)

Monthly Savings	Geostar 2.0	OmniTRACS & Geostar 2C
$20	14.0	17.0
40	7.0	8.5
80	3.5	4.3
160	1.8	2.1

c. Net Present Value

Unlike the payback period, the change in net present value is constant with an increase or decrease in monthly return after expenses. However, changing the discount rate will result in a different net present value. For Geostar System 2.0, breakeven or zero NPV at a 10% discount rate occurs at approximately a $23 return per month. The 21% rate from the MRB study requires approximately a $50 return beyond all monthly expenses to reach a zero NPV. Roughly $27 is required for OmniTRACS and Geostar System 2C to reach zero

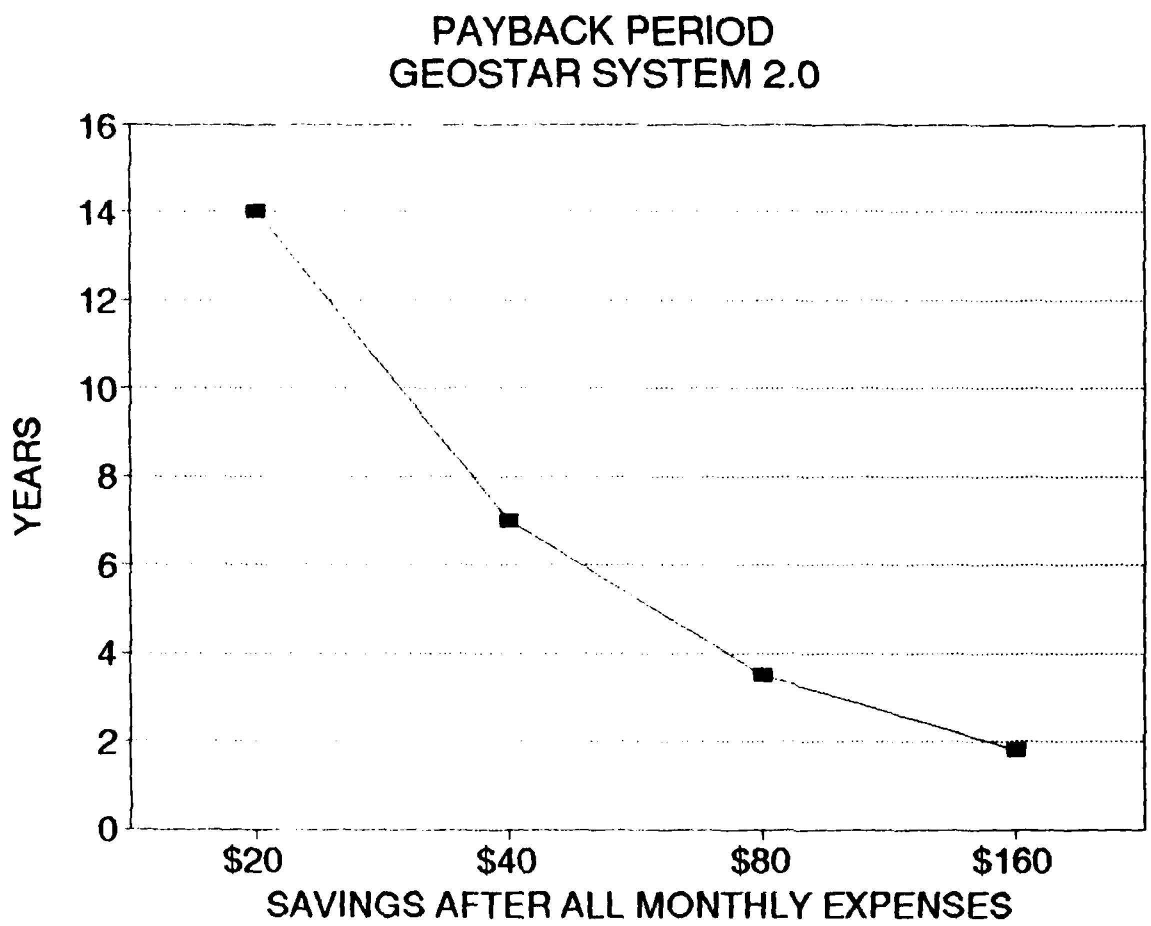


Figure 62. Payback Period, Geostar System 2.0

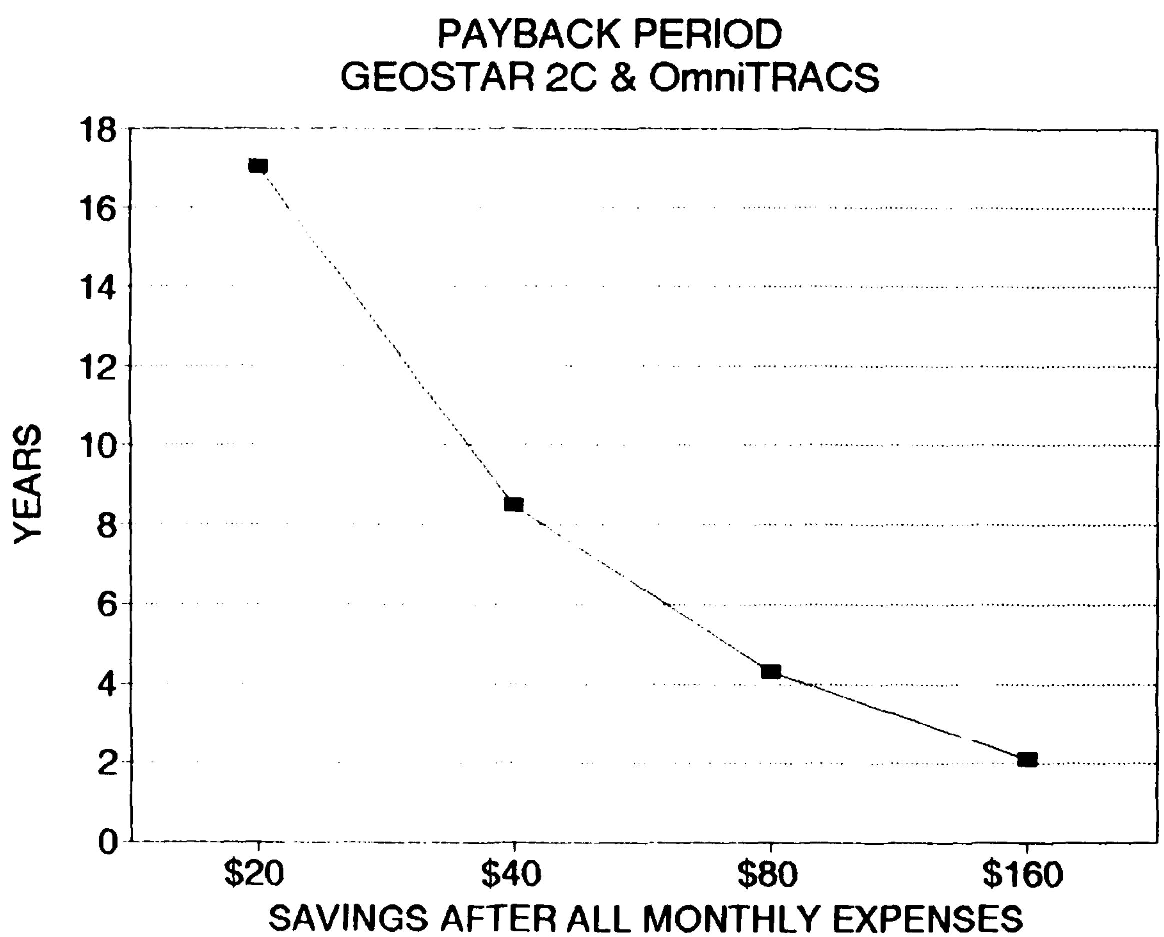


Figure 63. Payback Period, Geostar 2C and OmniTRACS

NPV at 10%, while a $62 return is required at 21%. Figures 64 and 65 contain graphs of the data listed in Table 16.

TABLE 16

NET PRESENT VALUE SENSITIVITY--GEOSTAR SYSTEM 2.0

	Discount Rate		
Monthly Savings	10%	15%	21%
($40)	($2145)	($2245)	($2348)
0	(765)	(1046)	(1320)
40	615	153	(293)
80	1994	1352	735
120	3374	2551	1763
160	4754	3750	2791
200	6133	4949	3819

TABLE 17

NET PRESENT VALUE SENSITIVITY--OmniTRACS & GEOSTAR 2C

	Discount Rate		
Monthly Savings	10%	15%	21%
($40)	($2309)	($2469)	($2632)
0	(930)	(1270)	(1604)
40	450	(71)	(576)
80	1830	1128	452
120	3210	2326	1480
160	4589	3525	2507
200	5969	4724	3535

d. Internal Rate of Return

The internal rate of return (IRR) is the NPV formula solved for the particular discount rate which forces the NPV to zero. The change in IRR is not constant and is

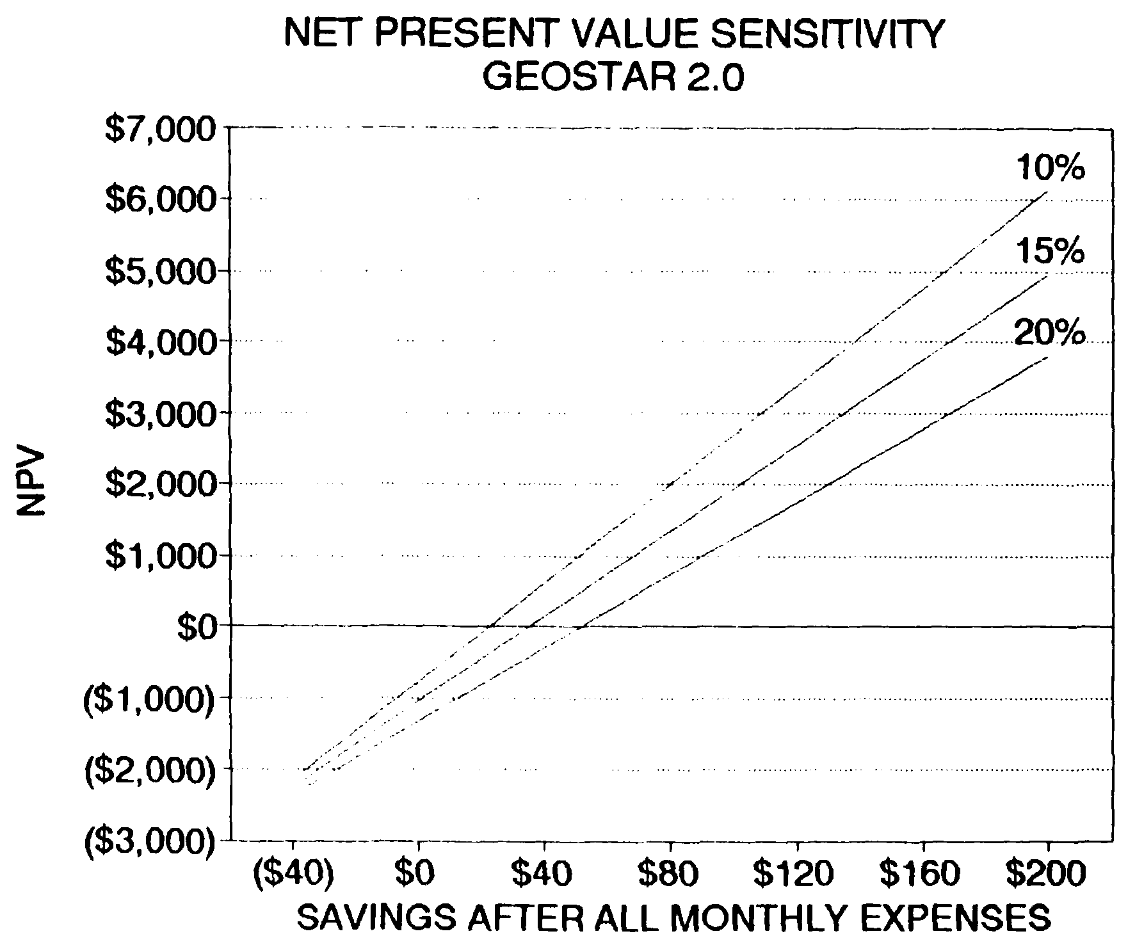


Figure 64. Net Present Value Sensitivity, Geostar 2.0

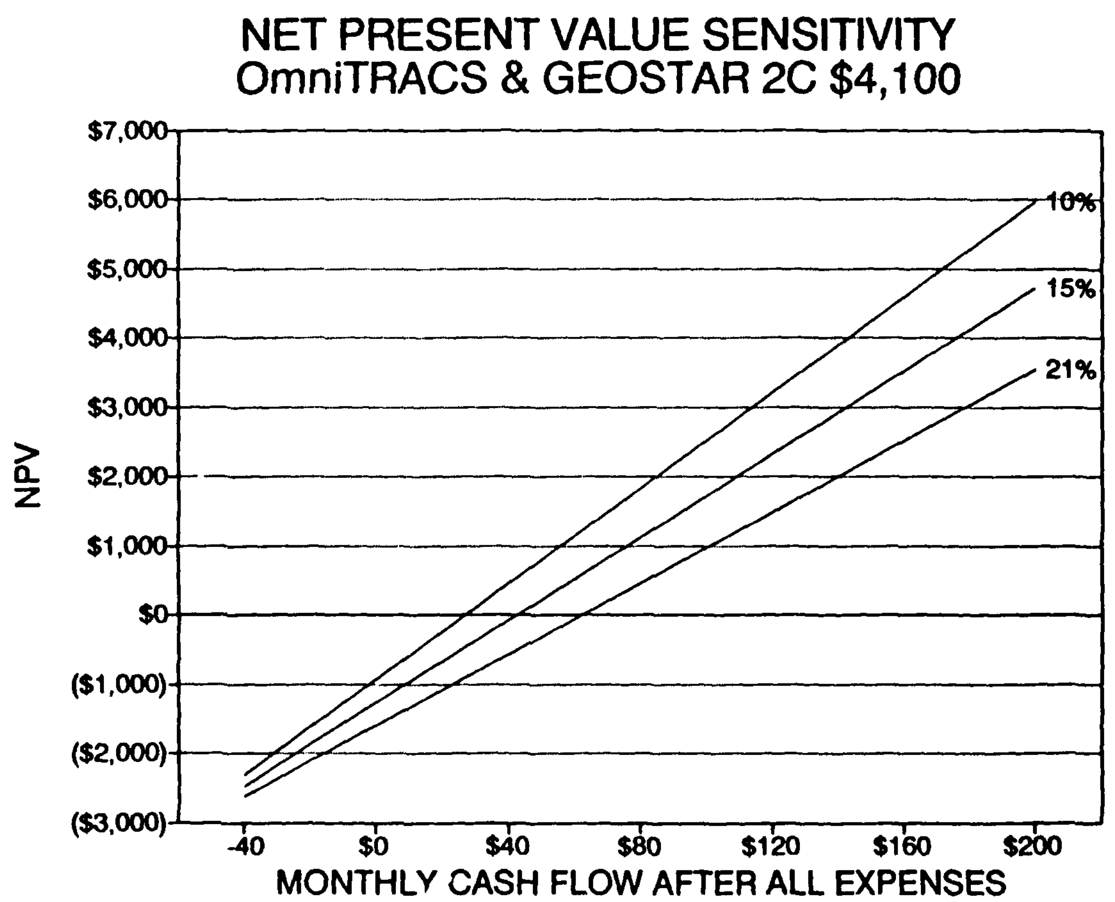


Figure 65. Net Present Value Sensitivity OmniTRACS and Geostar IIC $4100

largest at the lower end of the savings range. The data listed in Table 18 are graphed in Figures 66 and 67.

TABLE 18

INTERNAL RATE OF RETURN SENSITIVITY

Monthly Savings	GEOSTAR SYSTEM 2.0	OmniTRACS & GEOSTAR SYSTEM 2C
$ 0	0%	0%
20	9	8
40	18	15
60	24	20
80	31	26
100	37	32
120	43	36
140	48	41
160	54	46
180	59	51
200	65	55

J. COMPARISON OF MODEL OUTPUT WITH ACTUAL OPERATING STUDIES

1. Background

The consulting firm of Ernst and Whinney (Washington, D.C.) studied two Class I trucking firms which used Geostar equipment on a portion of their fleets. Frederick Transport was evaluated between 15 September 1988 and 15 October 1988 using Geostar System 2.0 equipment [Ref. 50]. KLLM Transport used System 2 plus a nationwide pager, and was studied from November 1988 through January 1989. The results of the KLLM study were used to extrapolate the savings which would accrue from using Geostar 2C equipment [Ref. 51]. The studies were not scientifically conducted and did not employ statistical

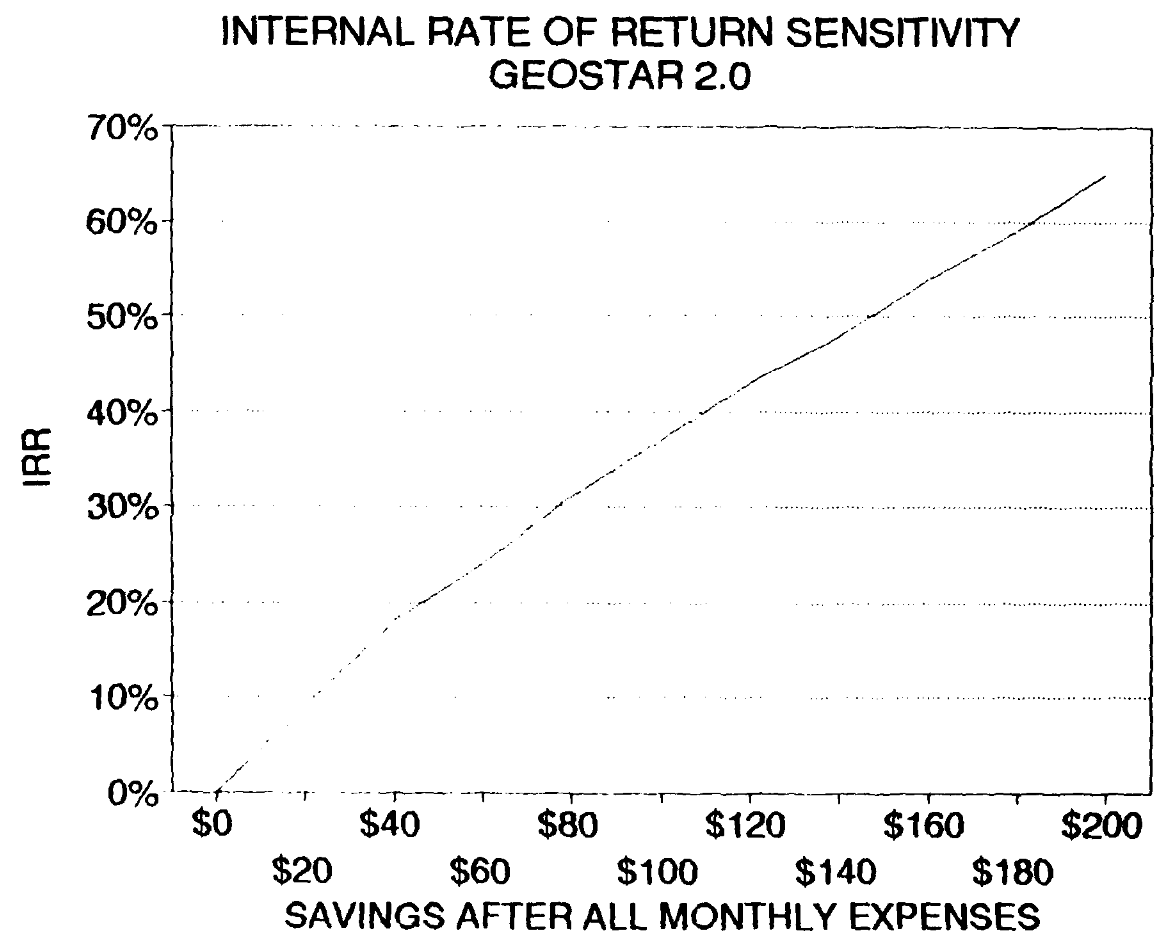


Figure 66. Internal Rate of Return Sensitivity, Geostar 2.0

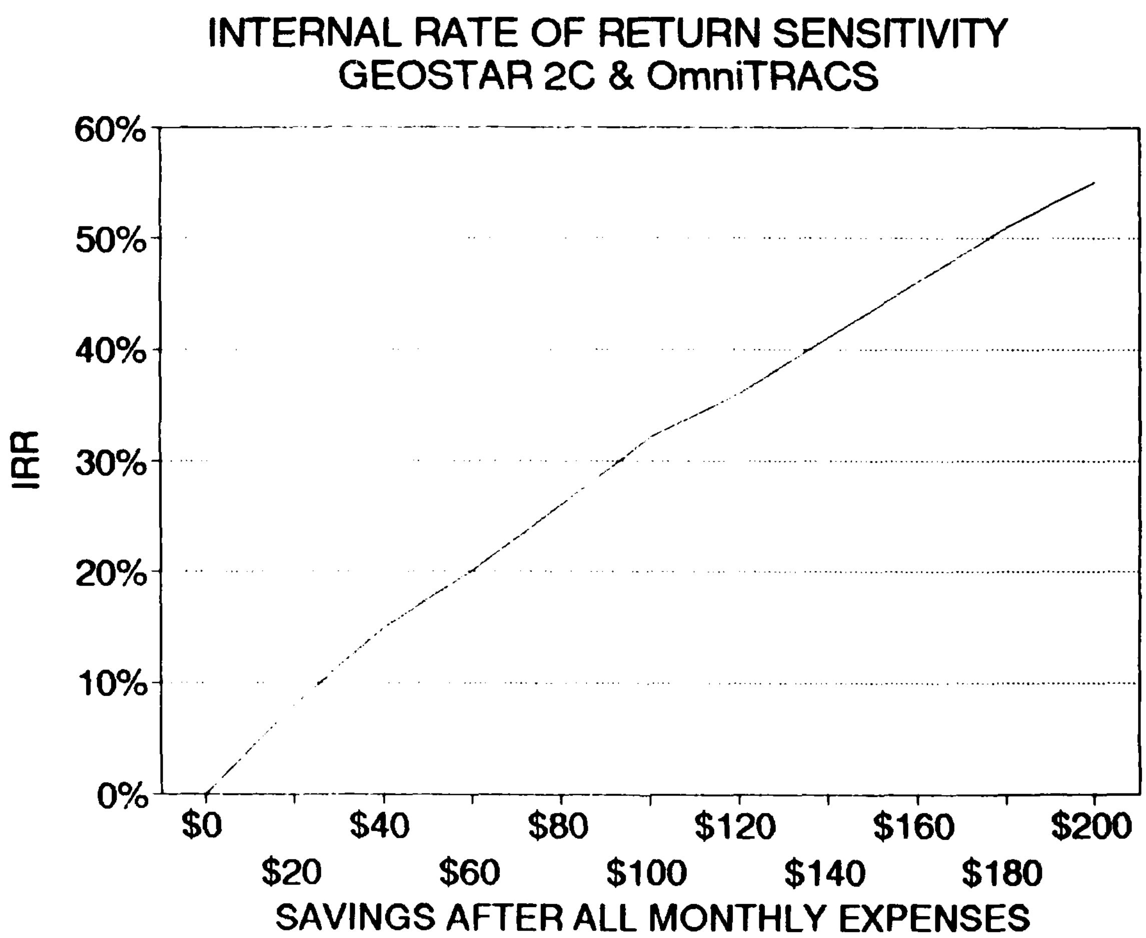


Figure 67. Internal Rate of Return Sensitivity, Geostar 2C and OmniTRACS

sampling techniques. However, every effort was made to isolate efficiency gains attributable to the Geostar system. The study results did not include monthly costs for Geostar service or communications with the Geostar network management facility.

2. Summary

Frederick achieved a 9.5% increase in equipment utilization mileage primarily because of a reduction in communication stops. Dollar savings were computed based on fixed equipment cost divided by the additional miles driven. A 0.72% reduction in empty miles (dollar savings measured as variable costs per mile multiplied by the reduction in empty miles) and a 50% reduction in telephone calls were also achieved. It was estimated that Frederick would be able to increase the driver to dispatcher ratio from 32:1 to 45:1. Annual savings per tractor were calculated as $2777. The assumed $4100 System 2.0 equipment purchase price would be financed over a three-year period with an 11% interest rate, yielding a net yearly savings of $1166 or $97.16 per month.

In the case of KLLM, survey tractors achieved an 8.9% higher equipment utilization, operated 0.84% more loaded miles, and drivers made two less phone calls per day. It was assumed that with the use of System 2C an additional two calls per day would be saved. Based on these assumptions, annual savings per tractor were calculated as $3210. Using an

estimated System 2C price of $5900 financed at 12% over five years, net yearly savings would be $1635 or $136.25 per month.

3. Equipment and Monthly Cost Adjustments

The above savings require adjustment because Geostar equipment prices have changed since these studies were made. In addition, the recurring costs of service and communications with the NMF must be factored in to determine the approximate net benefits. Adjusting the System 2.0 cost downward to $3375 and adding in a $45 per month service charge results in a revised savings of about $912 per year or $76 per month. Likewise, adjusting the System 2C costs to $4100 and including the monthly service charge results in yearly savings of about $1584 or $132 per month. The additional costs for communications with the Geostar NMF are unknown and therefore are not included, but they will reduce the calculated savings.

4. Comparison with the Model Output

The results of these studies cannot be directly compared to the model output because of the different methodologies, assumptions, and statistics used. The spreadsheet model evaluates cash flow increases from additional loaded miles and cost reductions, whereas the Ernst and Whinney studies evaluated only cost reductions. The net benefits calculated in the Ernst and Whinney studies would have been higher if they included the effects of additional revenue from more efficient utilization of trucks.

Both Frederick and KLLM experienced significantly more tractor miles per year (roughly 101,000 to 120,000) than used in the model (approximately 57,000 to 71,000). Loaded milage for both these carriers was between 88% and 90%, as compared to the 75% and 85% assumptions used in the model. Variable costs per mile were also lower, with KLLM at $0.68 as compared to roughly $1.00 per mile used in the spreadsheet analysis. However, the most significant difference was the reduction of empty miles. Whereas the model used 5% and 10% increases based on the MRB study, the carriers only achieved between a 0.7% and 0.9% increase.

These differences are probably due to a combination of how efficiently the two fleets are managed and the way model trucking firm operating statistics and costs were determined from macro ICC data. A further examination of the differences between the spreadsheet model and the Ernst and Whinney studies is beyond the scope of this thesis.

K. CONCLUSIONS

1. Limitations

As discussed above, the spreadsheet model output is strictly qualitative. The actual costs, revenues, and milage statistics for each firm will differ from the model categories.

2. Industry Segments

The MRB study determined that the average trucking company target return on investment (ROI) for communications related equipment was 21% and the target payback period averaged 3.6 years [Ref. 49:pp. 25-28]. As calculated by the model, these criteria are generally exceeded in those categories where the contribution margins and productivity increases are greatest. The industry categories which do not meet these goals have lower contribution margins. This makes it more difficult to completely offset the additional costs of a satellite system through productivity increases and cost reductions. Additionally, if the typical empty-mile (deadhead) reductions are closer to those in the Frederick and KLLM studies (less than 1%), then the model calculations are overstated.

LTL and TL carriers moving over well-established route networks may not realize much savings from the use of a satellite system. These carriers already have a high percentage of loaded miles and they generally do not have to communicate very often by telephone. An exception to this may be in the area of just-in-time applications where vehicle location and estimated time-of-arrival information require extensive contact between the driver and the dispatcher.

Irregular route, long-haul carriers probably are the market segment which will benefit the most from satellite technology. The costs associated with deadheading and

telephone communication are the greatest in this portion of the trucking industry.

3. Use of a Nationwide Pager

From a financial standpoint, the use of a nationwide pager to provide limited two-way service is less economical than using Geostar 2C or Qualcomm OnmiTRACS equipment. This is because the cumulative monthly service charges exceed the additional costs of full two-way equipment. From an operational standpoint, the lack of full geographic downlink coverage will probably require more use of the telephone to ensure calls to the mobile unit were not missed.

4. Other Potential Savings

The qualitative analysis included only reductions in deadheading, communication stops, and costs for telephone communication. The analysis did not include revenue growth from being able to provide value-added services. Savings from avoided cost of capital, reductions in layover and dispatching costs, security, safety, insurance, maintenance, and other administrative expenses were also not included. Satellite communication and tracking technology may generate significant financial benefits in each of these areas.

5. Consideration of Alternative Systems

Satellite systems were chosen for evaluation because of their ubiquitous coverage and high equipment cost. Potential users should evaluate satellite system features, such as 100% coverage and almost real-time message delivery,

against their actual operational requirements. Depending on their pattern of operations and route structure, carriers may find that a reduction in coverage and message delivery speed is more than offset by lower equipment costs and user charges for alternative systems.

6. Deciding to Use a System

On the surface, the qualitative analysis suggests that using a satellite or alternate nationwide mobile communication and tracking system may make economic sense. In many cases this may be true. However, each trucking firm has a different cost structure and different operation. Before making a purchase or lease decision the potential user must thoroughly understand all of the costs involved, each system's capabilities, and the potential impact on the firm's operations. If these are not well understood then a thorough test and evaluation using a limited number of equipped trucks is suggested. Valid baseline data for comparison must be used when conducting the evaluation. Additionally, a method should be developed to factor out variations in operations that are not related to the equipment under test. This will help ensure that the correct procurement and operations decisions are made.

Even if the test results are favorable, some potential users may be reluctant to use nationwide communication equipment because of general uncertainty in the business environment, fear of new technology, and the promise of

lower-cost equipment and services in the future. However, systems which show a rapid payback should be seriously considered since the risk will be minimal.